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2024(2)

CONTENTS

南 方 建 筑 学 报

http://www.viserdata.com/journal/jsa

2024(2)

目 次

Contents lists available at Viser

Journal of South Architecture

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Discourse on Healthy Cities and Healing Environments

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ABSTRACT: The Central Committee of the Communist Party of China (CPC) and the State Council released a plan in October 2016 entitled "Outline of the Plan of 'Healthy China 2030'." The objective outlined in the plan was to "integrate health into the whole process of urban-rural planning, construction and governance, and promote the harmonious development between cities and human health." As an indispensable part of building a healthy China, the healing environment concept has proven integral to the physiological and psychological health of human beings. The early achievements made in the psychological science and rehabilitation fields have gradually impacted landscape architecture, urban planning and architecture. In modern high-density city settlements, particularly since the outbreak of COVID-19 in 2020, the importance of healing environments has been highlighted. In recent years, scholars have expanded on and deepened the research by investigating blue-green spaces at different levels, as well as the natural elements of a built environment. They have also attempted to utilize experimental means wherever possible, making remarkable progress in the process. The editorial department of this journal organized an academic conversation on the topic, Healthy Cities and Healing Environments. Six scholars from different backgrounds were invited to take part in a focused, yet diverse, discussion. Based on the relationship between green and health on the urban scale, Li Shuhua explained that cities are places where humans gather and live and, thus, such places continue to develop with the evolution of our species. An ideal city should conform to people's collective desire for a better life. It should not only meet the needs associated with sustainable ecological development but also provide people with an appropriate living environment in favor of human health. The Green Healthy City Theory provides an ideal perspective toward alleviating current "Urban diseases" and "Urban population health issues". The Otemachi Forest in the center of Tokyo represents a practical pioneering case of the Green Healthy City Theory. Based on relations between humans, nature and cities, the current study traced the development of ideal cities in Europe, America, Japan and China, and discussed the principles and constituent elements that should be adhered to during practical construction of a green healthy city. There are evident differences among different races in terms of the COVID-19 infection rate in the United States (US), which reflect health justice issues. Therefore, Jiang Bin et al. hypothesized that such differences among races are significantly reduced in areas where green space coverage is high. Taking control over variables covering socioeconomic characteristics and chronic diseases, the current study measured the correlation between racial differences in the COVID-19 infection

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rate and green space coverage using a multi-linear regression model. The findings from the study revealed that, at the county level, higher green space coverage could significantly reduce racial differences of COVID-19 infection rate. Further, four green space types were found to contribute to this reduction. Finally, an encircling mechanism and five core mechanisms were established to interpret such correlation. Du Hongwu et al. determined that it is extremely important that high-density urban scenery meet people's restorative needs, which were highlighted during the COVID-19 outbreak. Two types of sky gardens, which are grown outside well-designed office buildings and residential buildings, both promote restoration. However, their spatial morphologies, influential factors and action mechanisms differ. The spatial locations, combinations and relations between spaces should be arranged in a way that increases the restorative benefits of sky gardens. Toward improving the quality of sky gardens, the influential factors impacting the restorative benefits of sky gardens should be explored further. These include visual accessibility, the spatial level of sky gardens and the green view rates. It is also important to establish supportive environments, to strengthen multifunctionality, to diversify activity types and to increase participation and usage rates.Zheng et al. believed that green contact in cities is crucial for the promotion of urban residents' health. In practical projects, full consideration to functions and the use of streets has to be given to such green contact in order that the associated health benefits are realized. Combining the street reconstruction for a park city in Chengdu, Zheng et al. investigated the walking and business-facility use preferences of 40 respondents in specific street scenes as well as the green space alongside streets for the remainder of the behavioral experiment. Moreover, their first impressions and sub-dimensional evaluation findings of the street environment were collected. At the same time, eye positions of respondents in their relevant choices or evaluations were recorded using an SMI Redn Professional desktop eye tracker. The results of the study provide support for decision- making in the design of healthy streets. Long Hao attempted to review and elaborate on the specific applications of evidence-based design in the design and construction of rehabilitation gardens. He believed that as an important psychological and physiological rehabilitation space in CCRC- type aging communities, rehabilitation gardens should be implemented to improve functions of gardens in psychological counseling based on evidence-based design. The psychological health, depression and anxiety of the aged residents are becoming increasingly prominent issues as the closed management in medical and nursing institutions for the aged is becoming increasingly common as a result of COVID-19. It is expected that the current study will provide reference points and assistance in thinking about rehabilitation garden design into the future and offering a feasible psychological health space for CCRC-type aging communities. Focusing on the age-friendly city framework of the World Health Organization (WHO), Yuan Xiaomei proposed the concept of a "community environment of health management for the aged." This concept helps to establish the key technological system of "the aged + environment + life" from the perspectives of "comfort and safety", "encouragement in activities", "intimacy to nature" and "interaction." She aims to integrate rehabilitation therapy into daily outdoor activities for the aged and provide them with an effective environmental solution to their health-and life-related issues. In the current study, the health performance and application potential of relevant technologies were described through their combination with the findings of the preliminary research and evidence-based practices put forward by the research team led by Professor Yuan Xiaomei.

KEY WORDS: *healthy city*; *healing environment*; *green healthy city*; *health justice*; *health benefit*; *rehabilitation community*

"Green Healthy City" Theory

by Li Shuhua

Cities are places where human beings gather and live, evolving continuously with human progress. An ideal city should embody people's aspirations for a good life, meeting the requirement of green development for ecological sustainability while providing a suitable living environment that benefits human health. The theory of "Green Healthy City" represents one of the ideal models to alleviate the "city diseases" and "citizens' diseases", with Tokyo's central district "Otemachi Forest" serving as a pioneer case for this theory.

1 Reflections inspired by "Otemachi Forest" in Tokyo's city center

Otemachi is located in Chiyoda on the eastern side of the Imperial Palace in central Tokyo, known for its concentration of skyscrapers and luxury hotels, making it one of the highest-density areas in Tokyo. This project aims to reintroduce nature and wilderness into urban spaces, creating a new form of urban public space to evoke, by expressing the vitality and profoundness of nature, a sense of a natural "forest" in the city, allowing people to experience the original natural beauty of the earth.

2 Urban development theory and practice based on the relationship between human and nature

Cities evolve to meet the needs of human production and livelihood, with early developments focusing on practical needs such as defense, politics, transportation, and trade in relatively small scales, constrained by productivity and population growth to a slow development. The influx

of rural populations into cities during the Industrial Revolution brought about fundamental changes in urban development, leading to various challenges, among which the discussions and explorations regarding the relationship between human and nature have been ongoing since then.

2.1 Development of urban theories and practices in Europe and America

The Industrial Revolution in the 18th century greatly enhanced social productivity, leading to the urbanization phenomenon in the western countries as the agricultural population and land shifted to cities in the late Industrial Revolution period. The rapid growth of urban populations brought significant economic benefits but also gave rise to various negative issues. Green spaces and public areas were encroached upon by poorly planned residential areas. Poor sanitation conditions, water pollution, and large-scale population movements led to the proliferation of bacteria and contagious diseases. In the first half of the 19th century, infectious diseases such as cholera, typhoid fever, and yellow fever broke out multiple times in countries like England and the United States, posing serious threats to public health. The fast economic development juxtaposed with poor health conditions and significant population deaths drew attention from various social classes. Western countries, represented by the UK and the US, began reflecting on their urban development models and proposed different strategies and theories in response.

In 1898, the British social activist Ebenezer Howard introduced the Garden City theory, aiming to establish a healthy, natural, and economic combination between cities and their surrounding agricultural lands to provide abundant job opportunities for urban residents and enhance their health and living standards. Around the same period as the proposal of the Garden City concept in the late 19th century and early 20th century, the United States witnessed the "City Beautiful Movement" frenzy. This movement also fostered the development of comprehensive, multi-objective urban planning concepts. During this time, cities like Washington, San Francisco, and Chicago achieved notable success in implementing related planning and designs.

In the 1940s, various cities in the UK began constructing and opening public green spaces, providing green areas to the public in the form of parks and urban green belts in cities like London, Manchester, and Nottingham. In 1858, landscape architect Frederick Law Olmsted led the planning of Central Park in New York and later designed a series of city parks in places like San Francisco and Detroit, propelling the practice of the "City Park Movement" in the United States. Good sanitation conditions and ample green open spaces became effective means to address public health issues.

In the mid-20th century, under the influence of sustainable development and systematic thinking, the ecologically oriented concept that integrates social, economic, and natural factors began to emerge as the leading ideology in urban development.

2.2 Development of urban theories and practices in Japan

In 1907, Howard's Garden City theory was introduced and promoted by the Japanese Ministry of Internal Affairs, sparking societal responses. In 1918, Eiichi Seizo, a prominent figure in the Meiji industrial sector, established the "Garden City" Corporation and developed the garden-style upscale residential area "Garden Tama City" in Chōfu-shi near the Tamagawa in Tokyo. In 1991, Kazuhiko Takeuchi, in line with the realities of Japanese urban development, put forward the concept of a "Green Agricultural City" based on the Garden City concept, primarily addressing Japan's challenge of creating large circular green belts similar to those in Europe and America due to high levels of urbanization. The proposal suggested the allocation of scattered agricultural and forestry areas on the outskirts of cities, advocating for the flexible utilization of the complementary advantages between urban and rural areas to form an environmental network.

2.3 Development of urban theories and practices in China

In the late 1980s, China actively responded to the UNESCO's initiative for building ecological cities. Several relevant departments successively proposed different standards for assessing advanced city construction, laying out interim indicators for eventually establishing ecological cities. In 1992, the Ministry of Construction initiated the activity of building "National Garden Cities." On this initiative, in 2004, the Ministry of Housing and Urban-Ru-

ral Development began the construction of "National Ecological Garden Cities." Compared to Garden Cities, the standards for Ecological Garden Cities included additional indicators reflecting biodiversity, public satisfaction with the ecological environment, etc., comprehensively assessing the composite development of urban artificial environments and natural ecological environments. Building upon ecological principles, research and practices focusing on Forest Cities, Sponge Cities, and others have been ongoing. Since 2010, urban resilience has also been receiving increasing attention and application.

3 "Green Healthy City" Theory

3.1 Principles of constructing "Green Healthy Cities"

In essence, a green city is an eco-friendly city, a healthy city is one that promotes the physical and mental well-being of its residents, and a "Green Healthy City" is a composite term that combines the characteristics of both green and healthy cities. A Green City serves as the foundation of a Healthy City, and a Healthy City is the objective of a Green City. To meet the requirements of a city's eco-friendly environment and the physical and mental well-being of its residents, the following principles should be adhered to in urban green space construction: (1) rich biodiversity and the establishment of natural-like artificial ecosystems are the foundation for sustainable development of urban environments. (2) Symbiosis and circulation are the basic principles for urban green space construction in the context of a low-carbon society. (3) From tree planting and grass seeding to ecological restoration and natural regeneration. (4) In the selection of green space plants, native plants should be the primary focus. Avoid non-healthy plants. (5) Understanding nature is the most fundamental attribute of humans. (6) Urban green spaces are essential factors in guaranteeing the physical and mental well-being of citizens.

3.2 Elements of "Green Healthy Cities"

In ensuring rich biodiversity in green environments and the sustainable and healthy development of urban environments, as well as improving the physical and mental health of urban residents, increasing the index of happiness and quality of life, the constituent elements of "Green Healthy Cities" include: (1) ecological green web system intersecting water and greenery; (2) urban green spaces designed as biotope habitats; (3) water-friendly near-natural river corridors; (4) health-oriented ecological road corridors and avenues covered with trees; (5) woodlands and large trees with health benefits both for the urban environment and the physical and mental well-being of citizens; (6) building aerial ecological corridors primarily consisting of rooftop gardens and green wall installations; (7) elevated bridge ecological green corridors, with elevated bridges being common large-scale structures in modern cities; (8) environmentally symbiotic housing; (9) flower-lined streets; (10) ecological health trails; (11) vibrant and engaging community gardens and citizen parks; (12) encircling green belts (green rings).

In addition to the aforementioned elements, the refinement of urban water circulation systems, slope greening systems, permeable paving, and green waste recycling systems are also essential for constructing "Green and Healthy Cities."

Conclusion

How to establish a stable and sustainable urban environment that maintains vitality, while also being comfortable, beneficial, and cultural, ensuring that urban green spaces fulfill six major functions of ecological conservation, landscape beautification, rest and recreation, cultural heritage, disaster prevention, and health and hygiene, remains an eternal topic in the landscape architecture industry.

Landscape Justice: The Significant Relationship Between Provision of Green Spaces and Racial Disparities in COVID-19 Infection Rates in the United States

by Jiang Bin

1 Research highlights

This study is one of the pioneering research efforts to explore the racial disparities in COVID-19 infection rates between Black and White populations in relation to green spaces. A nationwide study was conducted across 135 counties in the United States, with the highest levels of urbanization covering 40.3% of the national population. After controlling for confounding variables, the study found

that higher coverage of various types of green spaces corresponded to smaller racial disparities in COVID-19 infection rates. The study established one peripheral mechanism and five core mechanisms to explain its findings.

2 Research background

Many countries face disparities in health conditions among different racial groups, which can lead to social unrest, economic disputes, and even endanger residents' safety. The health disparities between Black and White populations in the United States are highly representative among developed economies. Since the onset of the COVID-19 outbreak in 2019, the differences in COVID-19 infection rates among different racial groups in the United States have become more pronounced. Previous studies have shown that green spaces may have a positive and independent impact on reducing health disparities between racial groups. However, there has been limited research focusing on the relationship between green spaces and racial disparities in COVID-19 infection rates, as existing studies mainly concentrate on socioeconomic factors and chronic disease factors. There is a wealth of evidence and theories demonstrating the multi-spatial scale and multi-pathway positive impacts of green spaces on resident health. Therefore, we hypothesized that providing green spaces could alleviate racial disparities in COVID-19 infection rates, with regions having higher green space coverage showing significantly lower Black-White racial differences in COVID-19 infection rates.

3 Research design

We compared the racial disparities in COVID-19 infection rates between Black and White populations in 135 highly urbanized counties, while controlling for confounding variables. In this study, "Black-White racial disparities" were defined as the difference in COVID-19 infection rates between Black and White individuals within the same county, which greatly reduces bias caused by variations among counties (including climatic conditions, medical conditions, regulatory policies, etc.). We employed an internal comparison (within counties) research design and conducted statistical analysis and research on a nationwide scale. The COVID-19 infection data were sourced from official websites of public health government agencies in each county, with data collection up to July 10, 2020.

4 Analysis results

Through data analysis, we identified the following key findings: (1) the infection rate among Black individuals is on average double that of White individuals. (2) Significant disparities exist in COVID-19 virus infections among different racial groups. (3) Model 1 shows a significant correlation between socioeconomic variables and racial differences in infection rates. (4) Model 2, after adding existing chronic disease variables, showed a slight decrease in significance but still remains associated with racial differences in infection rates. (5) Model 3 demonstrates that the independent impact of green space variables is greater than other variables, resulting in an 18% increase in explanatory power. Specifically, there are four green space variables which are significantly related: open space, forests, shrubs, and grasslands.

5 Discussion

Based on experimental and theoretical assessments of the influence of environmental factors on disparities in COVID-19 infection rates, this study has identified a peripheral mechanism and five core mechanisms.(1) Peripheral Mechanism: in counties with higher green space coverage, Black and White individuals are more likely to equally enjoy the health benefits of green spaces. An increase in green space availability may provide Black individuals and their communities with sufficient green spaces; inadequate green space supply tends to favor White individuals and White communities. (2) Core Mechanism 1: environmental factors have a social aspect and attract people to outdoor spaces. Existing research indicates that people prefer places with vegetation over barren urban spaces. Such areas can mitigate virus transmission through three main pathways: 1) outdoor air circulation slows virus spread; 2) green outdoor spaces encourage outdoor activities and prolonged outdoor stays; 3) maintaining social distancing is easier outdoors. (3) Core Mechanism 2: urban green spaces provide all races with equal opportunities to connect with nature and offer outdoor activity spaces during the pandemic. Outdoor activities can boost immune functions more effectively than indoor activities. (4) Core Mechanism 3: green spaces in cities contribute to people's

mental health. Studies show that Black individuals endure more mental stress, particularly evident during the pandemic. Green spaces help alleviate mental fatigue and stress, reducing negative emotions. (5) Core Mechanism 4: urban green spaces enhance social health by reducing impulsivity and extreme emotions, promoting communication and social connections among people. (6) Core Mechanism 5: urban green spaces improve air quality and reduce air pollution, resulting in lower infection rates. Black communities often have higher population densities and poorer air quality compared to White communities; increased green spaces can enhance air quality levels.

Conclusion

This study represents the first attempt to understand the relationship between environmental factors and racial disparities in COVID-19 infection rates. We utilized multiple linear regression models to interpret the racial differences in COVID-19 infection rates between Black and White populations at the county level. After controlling for socioeconomic variables, chronic disease variables, and urbanization level variables, we found that higher forest, shrub, and grassland coverage significantly reduces the racial gap in COVID-19 infection rates between Black and White populations. Counties with higher green space coverage exhibit lower racial disparities in COVID-19 infection rates. Furthermore, providing green public spaces in urban environments can mitigate racial disparities in COVID-19 infection rates through various influencing mechanisms. This study demonstrates the potential of green spaces in alleviating health disparities between racial groups and creating a healthy living environment.

Sky Gardens in High-Density Urban Living and Their Restorative Benefits

by Du Hongwu

Starting from the 1960s, the aesthetics and visual preferences of built environments have been emphasized by environmental psychologists, leading to a series of discoveries that prompted further research on the impact of nature on individual psychological and physiological well-being and how biophilic design can be utilized to enhance human psychological and physiological health.

The development of contemporary high-rise buildings has met the demand for more significant spaces but has also disconnected people from close contact with natural elements.The lack of daylight, natural ventilation, and potential isolation from the outdoors can lead to physiological diseases and building-related illnesses such as Sick Building Syndrome (SBS). Research indicates that stress, boredom, irritability, and other psychological conditions are often associated with poorly designed high-density living environments. Natural elements such as green spaces and water scenery serve as crucial restorative elements with benefits like stress reduction, mood enhancement, and cognitive improvement.

For high-density cities, providing opportunities for restorative experiences in everyday life scenes is particularly vital. However, high-density urban spaces greatly restrict the connection between individuals and regenerative environments on the ground, a situation exacerbated by the COVID-19 pandemic.

Sky gardens, as essential spaces for creating regenerative environments, are increasingly demonstrating the positive value. While their regenerative potential has been preliminarily confirmed, relevant research has not received sufficient attention. The complex relationship between the formal elements of sky gardens and their regenerative benefits still remains largely unexplored. In this context, sky gardens refer to elevated recreational environments above ground level, featuring landscape elements, with or without canopy, open or enclosed, and diverse forms. They represent a primary spatial element and design language in contemporary architecture, serving as alternative social spaces that offer multi-dimensional values in high-density cities, including societal, ecological, economic, and health benefits. This study explores the regenerative benefits of sky gardens in high-rise office buildings and high-rise residential buildings.

The study, incorporating numerous case studies in the Pearl River Delta region, identifies key factors influencing the restorative benefits of sky gardens through on-site investigations and literature reviews. In the context of high-rise office buildings, these key factors are selected as three groups of variables, including spatial forms (points, lines,

surfaces), spatial interfaces (glass curtain walls, window sills), and sky visibility (visible, non-visible). By permutating these variables, 12 different aerial courtyard VR experimental scenes are generated along with 2 control scenes without sky gardens, totaling 14 scenes. Participants are equipped with VR glasses and galvanic skin response sensors to record data on their responses during the laboratory stress process and subsequent recovery stages.

Various research methods commonly utilized for assessing health benefits have distinct advantages and focal points. Considering the challenges of data collection and equipment conditions, this experiment employed two physiological indicators - heart rate variability (p-p interval) and skin conductance response (SCR), along with a measure of psychological state - scores from the Profile of Mood States (POMS), to evaluate the health status of participants and indirectly infer the restorative effects of the experimental settings.

Past studies have confirmed that the mechanisms of stress recovery in individuals of the same age group are highly similar. Due to difficulties in recruiting participants and arranging experimental sites, 16 college students were randomly selected as subjects instead of office employees.

The experimental data confirmed the positive influence of the VR sky courtyard scenes on physiological and mental health recovery. Further exploration of the relationship between the characteristic elements of sky courtyards and their restorative benefits led to the following conclusions: (1) sky courtyards in high-density urban office buildings have restorative effects. Adding sky courtyards when the sky is not visible serves as an effective design strategy to enhance restorative benefits. (2) The presence of the sky alone in high-density environments does not show significant health benefits, but when combined with sky courtyards and natural elements, it can exhibit pronounced restorative benefits. Other restorative factors, when paired with visible skies, can enhance restorative effects. (3) The spatial form and interfaces have a non-significant impact on the restorative benefits of sky courtyards. (4) Sky courtyard scenes with specific feature combinations demonstrate noticeable healing benefits.

For the restorative benefits of high-rise residential sky gardens, a similar or analogous experimental design to the above study was employed, with the addition of the State-Trait Anxiety Inventory - State version (STAI-S) and theRestorative

Component Rating Scale (RCS). Through field research and survey analysis of the spatial characteristics of residential sky gardens and residents' restorative needs, three primary influencing factors were selected: space types (balcony, courtyard

, overhead sky gardens), space interfaces (real interfaces, virtual interfaces), green view rates (high, low), constructing 15 different VR scenes (including 3 control groups) and conducting restorative benefit experiments with 36 participants.

By collecting and analyzing physiological and psychological data from participants, the following conclusions were drawn: (1) residential sky gardens exhibit both physiological and psychological restorative benefits with specific feature combinations. (2) All three types of residential sky gardens demonstrate restorative benefits, with the compatibility dimension scoring the highest in the Perceived Restorativeness Scale results, indicating that the environmental settings in the experimental scenes align well with participants' expectations for regulating physiological stress, relieving psychological pressure, and improving anxious moods. (3) Significant differences exist in the physiological and psychological recovery benefits of balcony sky gardens with real and virtual interfaces. In the Perceived Restorativeness evaluation, distinct differences were observed in the ratings for the dimensions of escape and extension based on different spatial interfaces, indicating the significant role of visual transparency in alleviating anxious moods, particularly in smaller spaces, emphasizing the importance of visual transparency in the spatial interfaces. (4) Significant variations in the restorative benefits ofcourtyard and overhead sky gardens were observed based on the magnitude of green view rates, with a higher green view rate demonstrating superior restorative effects compared to a lower green view rate. Different levels of green view rates showed significant differences in ratings for the dimensions of fascination and escape, indicating that for larger-scale sky gardens, appropriately increasing

the green view rate can enhance the scene's appealing features and improve restorative benefits.

The aforementioned studies confirm that well-designed sky gardens in both office buildings and residential settings have restorative benefits. Nonetheless, there are clear differences in spatial forms and influencing factors, while their restorative benefits share similarities, their mechanisms of action are distinctly different.

Based on the conclusions of the aforementioned studies, to improve the restorative benefits of high-densityhuman settlement environments, the following actions should be taken: (1) recognize the significant value of sky gardens, address various constraining factors, and employ multiple measures to promote their development. (2) Plan the layout of sky gardens strategically, organize movement lines effectively, focus on the combination of different sky courtyards and spatial connections to enhance close contact between individuals and sky gardens. (3) Delve deeper into the influencing factors of the restorative benefits of sky gardens and enhance their spatial quality. (4) Establish supportive environments, strengthen multifunctionality, diversify activity types, increase participation and usage rates. (5) Enhance the visual accessibility of sky garden boundaries, enrich spatial and green landscape levels, and choose appropriate green view rates.

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Empirical Study of Green Healthy Streets Usage with Eye-tracking Support

by Chen Zheng

In research, it is often necessary to isolate the factors being studied from other influences for analysis. For instance, in studies of urban health-promoting streets, visible greenery and its health impacts are often isolated to discuss the effectiveness of green exposure and appropriate health dosages such as green view rates and exposure times. In the real world, streets serve multiple functions such as transportation, access to life service facilities, social interactions, fitness activities, and green exposure. The focus of actual projects often revolves around how to resolve conflicts between these functions. In highly greening yet functionally compromised lifestyle-focused streets, how can design strategies balance the sensory experience of greenery while mitigating the negative impacts on adjacent facilities? What design interventions can better encourage pedestrian activity and leisure green space utilization?

The "Chengdu Urban and Rural Spatial Planning (2016-2035)" proposes "Advancing Park City Street Construction and Enhancing Street Environment Quality." Against the backdrop of the Park City policy, Chengdu has introduced the "Chengdu Park City Street Integration Design Guidelines," guided by the "Park City Block Scene Theory" and the concept of "Street Integration," which are tangible manifestations of the idea of a beautiful and livable park city at the street level. Additionally, there are construction guidelines such as "The Way to Work" and "The Way Home." In the context of Park City development, as the street design paradigm shifts from being car-oriented to people-oriented, a series of issues have arisen: conflicting design concepts, pedestrian safety concerns, conflicts between business interfaces and greenery levels, and more. The problem with greening in urban development is not just about having a higher greening rate; it is more about design issues. Addressing the conflict between city greening and the usage of other functions while ensuring the basic functions of streets requires pinpointed street design optimizations based on more concrete street scenarios.

This paper shares an empirical eye-tracking study providing human decision-making support for the Chengdu Park City Street Renewal project conducted by the Urban Design Institute of Tongji Urban Planning & Design Institute, Shanghai Tongji Urban Planning Design and Research Institute Co., Ltd. We combined the "Chengdu Park City Street Integration Design Guidelines" with scenarios such as "The Way to Work" and "The Way Home" to further deepen the design strategies and conduct validation experiments.

In research, we combined experimental design with

planning design practice to explore the street transformation of Chengdu Park City through eye tracking and behavioral experiments. Using photographs, we conducted behavioral experiments with 40 participants to gather their preference choices for walking, dining, leisure activities on specific streets, as well as their initial impressions and multidimensional evaluations of the street environment. Simultaneously, we used the SMI Redn Professional desktop eye-tracking system to record participants' gaze patterns when making relevant choices or evaluations.

The results revealed that the removal of obstructive shrubbery and improvement of green space visibility elevated the overall dimensional evaluations and the vitality of the main functions of the pedestrian-friendly street while ensuring a sense of greenery. When pedestrians select amenities on lifestyle-focused streets, in addition to focusing on storefront facades, they also scan the external display spaces, awnings, and signage along the street to anticipate and compare potential purchasing experiences. Furthermore, in choosing walking paths, while street amenities still influence people's decisions, walkability and accessibility of the street become more critical decision factors. Removing obstructive shrubbery and enhancing the openness of the street's ground level can increase the accessibility of the above mentioned key information, effectively enhancing pedestrian foot traffic (from 35% to 88%) and commercial usage (from 25% to 88%). When selecting green leisure spaces, pedestrians primarily consider elements such as spatial enclosure, seating facilities, and other users that can help anticipate spatial usage experiences. Improving the accessibility of green spaces can significantly enhance pedestrians' recreational and walking activities.

By analyzing spatial attention and behavioral decision outcomes in the two typical activity scenarios of lifestyle-focused streets, we further deepen and expand the design principles and priority sequences of the "Chengdu Park City Street Integration Design Guidelines." In scenarios involving the use of lifestyle amenities, the preferred optimization includes increasing pedestrian area width, controlling green view rates in green belts, and increasing the density of street-front facades. Meanwhile, in scenarios involving the use of recreational green spaces along the street, the preferred optimization is to ensure appropriate green view rates.

Exploration of Evidence-based Design Theory in the CCRC Community Healing Garden

by Long Hao

At the beginning of 2020, with the release of the "Notice on COVID-19 Prevention and Control for the Elderly" and the "Guidelines for the Prevention and Control of COVID-19 in Elderly Care Institutions (2nd Edition)" by national authorities, elderly care institutions have generally adopted a closed management approach to address the threat of the pandemic. While closed management can prevent the spread of the virus, it has placed significant pressure on the operation and management of these institutions. From the perspective of the physical and mental health of the elderly, closed management has severed the visits of children and friends, leading to increased anxiety and depression due to pessimistic emotions related to the epidemic, thereby doubling the demand for psychological counseling services within institutions. In the context of the recurring and normalized epidemic situation, institutions that have effectively controlled the epidemic gradually began to reopen after about half a year, while institutions in regions experiencing recurrent outbreaks continued to alternate between open and closed statuses. In early 2021, the State Council stated that elderly care institutions had entered an emergency state of prevention and control for the winter and spring seasons, and various regions had successively initiated the closed management of elderly care institutions once again. Continuous Care Retirement Communities (CCRCs) in medical and nursing institutions, as comprehensive elderly communities with long-term care functions, are a crucial component. The psychological health issues among the elderly in the CCRC community caused by the current situation of closed management call for designers to rethink the design concepts and details in CCRC communities in our country. The Healing garden, as a crucial physical and psychological recovery space, assumes even greater importance under the normalized epidemic situation.

The concept of Healing garden or landscape has its roots dating back to ancient Greek times, with early developments seen in the Asclepius Temple within the Epidaurus Healing Sanctuary that advocated for the healing of patients through residential environments, physical exercises, and artistic expressions such as music. This interplay between mental and physical health with the surrounding landscape has been continuously proven in the medical field. A well-designed urban environment plays a significant role in improving residents' mental and physical health, often referred to as a "Restorative Environment" or "Recovery Environment."

In 1984, Professor Ulrich from the School of Architecture at Texas A&M University published an article in the journal "Science," titled "View Through a Window May Influence Recovery from Surgery." This study, using an evidence-based design approach, validated the correlation between natural landscapes and patients' recovery, becoming the origins of evidence-based design theory. Subsequently, theories like Stress Reduction Theory and Attention Restoration Theory continued to contribute to the theoretical development. In 1991, Professor Ulrich established the "Evidence-Based Design Supportive Theory," exploring the creation of optimal medical rehabilitation environments through scientifically validated methods from the perspective of healthcare facility design. In 2009, Hamilton proposed that "evidence-based design is a process: cautiously, accurately, and wisely applying the best evidence available from research and practice, in collaboration with informed clients, to formulate crucial decisions for each specific and unique project."

As evidence-based design has evolved over the years, professional certifications, databases, assessment tools, and models have seen significant advancements. Its scope has expanded from healthcare architecture to areas like landscape architecture, educational institutions, interior design, theaters, and more, playing a crucial role in the field of healing landscape design.

Amid the COVID-19 pandemic, the implementation of community lockdowns has directly led to a sharp reduction in the social circles of residents within CCRC communities. The usual 15-minute walking radius for social commuting has now shrunk to within the community or institution boundaries. The sudden residential isolation experienced in CCRC communities is not a result of traditional urban spatial soft segregations such as distance, wealth, cultural levels, or religion. Instead, it is driven by the rigid isolation enforced by disease outbreaks and policies, affecting not only residents but also staff members. While it is true that some large communities or institutions naturally form closed-loop living routes, limiting the elderly's departure from the community in daily life due to considerations of their behavioral abilities and safety, the subjective confinement and forced "lockdown" have distinct impacts on mental and physical health compared to normal levels of soft closure. Restrictions on individual freedom of movement can result in a range of adverse psychological manifestations, including depression, anxiety, emotional disorders, and impaired self-control.In CCRC communities, spaces for daily "exercise" and "activities" are limited to indoor areas within the institutions, making healing gardens essential outdoor spaces for activities.

The elderly population can be categorized based on their physical conditions as self-care seniors, assisted seniors, and care-dependent seniors. Normally, an Active Aging Community (AAC) or an All-Age Community typically comprises predominantly independent older adults who are fully self-sufficient and able to carry out their daily activities without relying on others for assistance. The design of healing gardens in CCRC communities should consider the behavioral characteristics and rehabilitation needs of elderly groups with different health statuses. It is important to note that due to the higher prevalence of illnesses among the elderly, the healing gardens they require differ from typical parks, as what constitutes an engaging garden for healthy individuals may have a different meaning for vulnerable groups such as patients.

Post-pandemic, the healing gardens in CCRC communities face a heavier task of psychological counseling, requiring finely tuned designs for emotional guidance and relief for the elderly in high-stress environments. The process mandates clear goal setting, prediction, and evaluation systems to transform the effects of landscape therapy spaces into medical metrics with clear utility and quantifi-

ability. In accordance with evidence-based design principles, the design should align with a scientific and clear approach. Specific considerations include:

Setting Rehabilitation Goals: the design of modern CCRC communities with rehabilitative gardens should be aligned with contemporary medical recovery assessment systems. Landscape elements should be designed based on the levels of rehabilitative activities conducted by the facility, in coordination with treatment plans such as Physical Therapy (PT), Activities of Daily Living (ADL), and Horticultural Therapy, to establish expected rehabilitation goals.

Evidence Collection: drawing upon research findings in rehabilitation medicine and landscape architecture both domestically and internationally, combining project practicalities with theoretical knowledge to undertake preliminary evidence-based work. Contemporary rehabilitative gardens have proven efficacy in addressing issues such as cognitive impairments, physical functional impairments, and psychological/emotional disorders, with evaluations conducted using measures such as the Mental Health Index (MHI) and the Geriatric Depression Scale (GDS).

Fit-for-Purpose Design: design should be rooted in relevant research, integrating the desired design goals with specific design strategies through a clear logical framework to avoid decision-making errors based on personal preferences or stereotypes. The generation of design logic requires an analysis based on feasible research, experiments, and simulation methods, with the data derived serving as the foundation for design concepts tailored to the specific analytical characteristics.

Outcome Prediction and Verification: traditional design processes often involve designers making informal predictions based on their experiences and project specifics, lacking an integrated validation framework and clear data statistics. Evidence-based design necessitates analyzing and predicting the impact of design strategies throughout the process, comparing them against rehabilitation goals, and subsequently validating assumptions through technical simulations or other methods to determine whether the expected outcomes align with the objectives. Post-Construction and Usage Evaluation: By conducting post-occupancy evaluations to gather data after the project's completion, the actual usage scenarios can be assessed against the anticipated goals, identifying discrepancies between assumptions and reality. Integration of findings into a centralized database allows for data archiving to support future design endeavors.

Overall, evidence-based design practices and research in the field of landscape architecture are relatively underdeveloped in China, with the absence of an Evidence-Based Healthcare Design and Landscapes (EBHDL) database. Both theoretical research and operational systems are still in the exploratory phase, and the application of context-specific operational systems has yet to mature, resulting in limited practical utilization in construction projects. Given the context of the pandemic, the normalization of closed environments in medical and elderly care communities emphasizes the need to place greater importance on the psychological guidance capabilities of rehabilitative gardens. Providing robust support for the mental health of vulnerable elderly populations is crucial to constructing resilient and healthy cities.

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Research and Design of Elderly-friendly Community Environments Based on Health Management

By Yuan Xiaomei

1 Concept of elderly-friendly community environments based on health management

As individuals age, various age-related chronic diseases continue to increase. Coupled with the natural decline in physical functions, the ability to live independently gradually diminishes, significantly impacting quality of life. According to statistics, elderly individuals in China, on average, spend more than 8 years living with illnesses (refer to "Several Key Points Emphasized by Sun Chunlan for Good Aging Work", China.com, 2019.10.09). Extending the healthy lifespan of older adults and ensuring their abil-

ity to live independently are urgent issues that must be addressed in active aging. This necessitates a shift in our public health system from traditional disease treatment to health management.

Broadly speaking, health management aims to improve quality of life and encompasses a series of management processes and methods that include disease prevention, treatment, and rehabilitation. As a non-pharmaceutical intervention, the environment can provide effective support for older adults' independent living and has been proven to be one of the most important health management measures to ensure the quality of life for older adults. The "Global Age-friendly Cities: A Guide" issued by the WHO in 2007 constructed a framework of age-friendly cities covering both physical and social environments across eight dimensions including "Space and Architecture," "Transportation," "Housing," "Social Participation," "Social Inclusion and Respect," "Civic Participation and Employment," "Communication and Information," and "Community and Health Services." Among these, "Space and Architecture," "Transportation," and "Housing" are placed at the forefront, highlighting the special importance of environmental design. Recently released "Opinions of the State Council on Strengthening Work for the Elderly in the New Era" (Xinhua News Agency, November 18, 2021) also includes creating age-friendly living environments as an important component of work for the elderly in the new era, posing new requirements for disciplines such as architecture, urban planning, and landscape architecture.

In alignment with the WHO Age-Friendly Cities framework, we propose the concept of "Elderly-friendly Community Environments Based on Health Management" (refer to Academic Paper Special Issue of "Architectural Journal", 2018(1):7-12), aimed at providing environmental support for older adults with different health conditions to promote a preventive-focused daily lifestyle. At its core is the integration of "elderly individuals + environment + lifestyle," forming relevant environmental intervention techniques.

2 Framework system of "elderly individuals + environment + lifestyle"

Early age-friendly environment design primarily referenced universal design standards, equating elderly individuals simplistically with people with disabilities. With the introduction of universal design and inclusive design concepts, designs for elderly environments have become increasingly refined. However, to this day, relevant technologies remain fixated on passive support for functional disabilities. Since the 1990s, the health benefits of nature have been continuously proven through scientific research, leading to the emergence of environmental intervention techniques that integrate the health benefits of nature, such as green care, green exercise, and forest medicine. These techniques offer new avenues for proactive health-oriented designs for elderly environments. Based on extensive research findings and practical cases, we conducted a comprehensive survey across various types of communities in Guangzhou, analyzing environmental issues that support healthy living for the elderly from the perspectives of "elderly individuals," "environment," and "lifestyle."

(1) Elderly individuals: in the surveyed communities, individuals aged 60 and above commonly suffer from various chronic illnesses and experience varying degrees of functional impairments, particularly in mobility, psychological functions, cognitive abilities, and sensory functions. Providing targeted environmental support can help reduce the incidence of age-related diseases, delay the decline in physical functions, assist in the recovery from illnesses, and significantly enhance the healthy lifespan of the elderly.

(2) Environment: present community environments pose varying degrees of safety risks. Current designs for elderly-friendly environments lack evidence-based support for health promotion. Some environmental designs may even have negative impacts, and the activity equipment provided in communities tends to cater only to individuals under 60, highlighting the urgent need for relevant foundational research to establish suitable design guidelines.

(3) Lifestyle: due to limitations in community environmental conditions, a significant portion of elderly individuals with functional impairments are unable to engage in independent outdoor activities, profoundly affecting their physical health and quality of life. Most outdoor environments primarily support static activities like chatting,

sunbathing, and napping, necessitating the provision of more suitable environmental support from a health promotion perspective. Survey results also indicate that independent gardening activities are prevalent in Guangzhou communities, especially among the elderly population, fostering a community environment that integrates the health benefits of nature and provides a solid foundation for a quality lifestyle.

Building upon research outcomes, we explored the holistic integration of "elderly individual + environment + lifestyle" from the perspectives of "comfort and safety," "activity promotion," "proximity to nature," and "interactive connections." We developed initial principles for designing elderly-friendly community environments based on health management and conducted evidence-based practices in institutions for the elderly in Guangzhou, achieving positive health outcomes.

3 Key technologies and evidence-based practices

" Renovation Project of Rehabilitation Garden in Ciyun Building" at the Guangzhou Elderly Care Facility is an environmental design project aimed at improving the physical, psychological, cognitive, and sensory functions of the elderly. This project was developed based on comprehensive research on the physical conditions of the elderly, existing environmental issues, and the health-related needs of daily life. The goal is to integrate medical rehabilitation treatments into the outdoor activities of the elderly to provide targeted environmental interventions that promote the physical and mental well-being of the elderly. Preliminary results from fall prevention experiments conducted in the rehabilitation garden at the Ciyun Building have shown significant improvements in the walking abilities of the elderly and have effectively boosted their enthusiasm for outdoor activities, thereby contributing positively to their overall well-being and encouraging their active participation (for more details, see doi: 10.3390/ijerph17197023).

During the outbreak of the pandemic, the Ciyun Building played a crucial role in isolating elderly residents of the Guangzhou Elderly Care Facility. The garden served as a space to alleviate the psychological stress of the elderly residents and healthcare workers, improving their emotional well-being and demonstrating the significant potential of environmental interventions in addressing public health issues. Such interventions could offer effective and low-cost solutions to alleviate the societal challenges and healthcare pressures arising from the aging population. Ongoing efforts continue to advance these initiatives, aiming to accumulate more experimental results to provide evidence-based support for the development of a health management-based system for elderly-friendly community environments.

Theresearch work is still being further advanced, and it is expected to accumulate more experimental results to provide evidence-based support for constructing an elderly-friendly community environment system based on health management.

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Construction of Multiple Paths for the Living Protection and Utilization of Traditional Villages: A Case Study of the Zhoutie Traditional Village in the Taihu Lake Area

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ABSTRACT: China is a vast country with a wide range of geographical and cultural differences, unbalanced economic development of traditional villages and housings, shortages in infrastructure and people's living conditions, prominent environmental and ecological problems, and an urgent need to improve the overall level of rural development. For a long time, the protection and utilization of traditional villages have mostly been based on the cognitive views of "frozen protection" and "one-sided protection", prompting difficulties and resistance in practice. Meanwhile, the result is not effective. At present, traditional villages encounter the situation of declining, hollowing out, and aging. Therefore, it is the theoretical frontier of traditional village research to get rid of the traditional one-sided and frozen protection model. Research should explore the living protection and utilization methods adapted to the characteristics of traditional villages and promote the close integration of traditional village protection and utilization with new development and construction.

Under the background of rural revitalization strategy and solving the critical problems of a lack of vitality, the decline and hollowing out of traditional villages are caused by "frozen" protection strategies. This is based on the extensive research and continuous study conducted by the "Key Technology and Integrated Demonstration for the Living Protection and Utilisation of Traditional Villages" of the "13th Five-Year Plan" key research project, especially the in-depth study of traditional villages around Taihu Lake. From the perspective of integrated development, it recognizes the dynamic interactions among the industrial status (production), regional natural resource (ecology), and historical living conditions (living). This can help fully coordinate industrial development and improvement of the living environment and ecological construction. Thus, traditional villages can obtain endogenous power for sustainable development. It also reveals that living protection and utilization are embodied in a systematic and orderly protection system under the simultaneous development of spatial dimension and temporal dimensions.

In the protection system, the coordinated development of spatial and temporal dimensions attaches importance to both the overall protection of the material space of traditional villages and the synergistic development of intangible culture and traditional villages in the time dimension. Its objective is to make the protection and utilization of traditional villages and the peoples' daily lives mutually promote each other, enhance the villagers' happiness and sense of achievement, and realize the sustainable development of traditional villages. For the theoretical approach, a multi-level path of living protection and utilization is constructed by combining spatial and temporal dimensions. Among them, the multi-level path in the spatial dimension is composed of three levels: the overall village layout, the individual building, and the indoor environment. The ephemeral path in the temporal dimension is progressively promoted by combining the immediate, medium, and long term, with intertwined interactions of the paths in temporal and spatial dimensions to achieve the living protection of traditional villages. Finally, the practical application of the above-mentioned mul-

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tiple paths is elaborated by taking the Zhoutie traditional village demonstration project in the Taihu Lake area as an example. Both perspective and practical explorations are conducted.

This study is on the construction of multiple paths of traditional villages in temporal and spatial dimensions with an elaboration of the Zhoutie traditional village in the Taihu Lake area. It is an example that will be a positive reference for the research and practical application of the protection and utilization of traditional villages in different regions of China towards an overall and dynamic 'living' protection and utilization model. Therefore, this study contributes to building traditional villages to gain continuous endogenous power and promote the sustainable development of traditional villages.

KEY WORDS: *traditional villages*; *living protection and utilization*; *multiple paths*; *multi-level paths*; *ephemeral paths*

Introduction

In China, the vast geographical diversity, differences in regional cultures, traditional villages, and residential architecture, uneven economic development, significant shortcomings in infrastructure and people's livelihood, as well as prominent environmental and ecological issues, all highlight the urgent need for overall improvement in rural development. For a long time, traditional village conservation and utilization have mostly adhered to the cognitive viewpoints of " frozen protection" and "one-sided protection," which have brought many difficulties and obstacles in practice, resulting in less than ideal outcomes [1]. Presently, traditional villages generally face a severe situation of increasing deterioration, hollowing out, and aging issues. Therefore, how to break away from the traditional one-sided and frozen preservation mode and explore the dynamic conservation and utilization methods adapted to the characteristics of traditional villages [2-6], integrating traditional village conservation and utilization with new development and construction, is at the forefront of current research on traditional villages [7-11].

In recent years, Professor Zhu Guangya's team at Southeast University, along with the team led by academician Wang Jianguo, conducted a long-term and in-depth tracking study on the traditional villages of Zhoutie in Yixing City, Jiangsu Province, in the surrounding area of Lake Taihu. This study, based on extensive research and continuous studies under the "Thirteenth Five-Year Plan" key research and development project "Key Technologies and Integrated Demonstration of Dynamic Protection and Utilization of Traditional Villages," constructed a multidimensional path of dynamic protection and utilization integrating spatial and temporal dimensions at the theoretical and methodological level. In terms of empirical application, using the demonstration project construction of the research team in the traditional village of Zhoutie as an example, the empirical application of the multidimensional path of dynamic protection and utilization was elaborated. The study explores the theoretical construction and practical application methods of the multidimensional path that are forward-looking and practical, which helps traditional villages gain sustainable endogenous dynamics, thereby partly alleviating the problem of hollowing out and achieving sustainable development.

1 Concepts related to dynamic conservation and utilization of traditional villages

1.1 Integration of production, ecology, and livelihood and their relationships with dynamic protection and utilization of traditional villages

Traditional villages have developed their unique physical space and cultural characteristics over thousands of years. The conservation practices of traditional villages in China have evolved from focusing on the preservation of living spaces to emphasizing the protection of living, and ecological spaces, and then to the concurrent protection of living, ecological, and production spaces, that is, the transition from the protection of livelihood to ecology and further to production [12]. Previous extensive research on traditional villages in China indicates that in discussing the dynamic conservation and utilization of traditional villages today, it is insufficient to solely focus on the "conservation" and "utilization" of the villages themselves. Instead, it is essential to adopt a holistic and systematic perspective. Starting from the integrated view of production, ecology, and livelihood, one should understand the influence of industrial conditions (production), regional natural resources (ecology), and historical humanistic

and residential conditions (livelihood) on the formation and development of traditional villages (Figure 1). By studying the overall and dynamic relationships between these factors and dynamic conservation and utilization, we can then establish diverse pathways for the dynamic conservation and utilization of traditional villages.

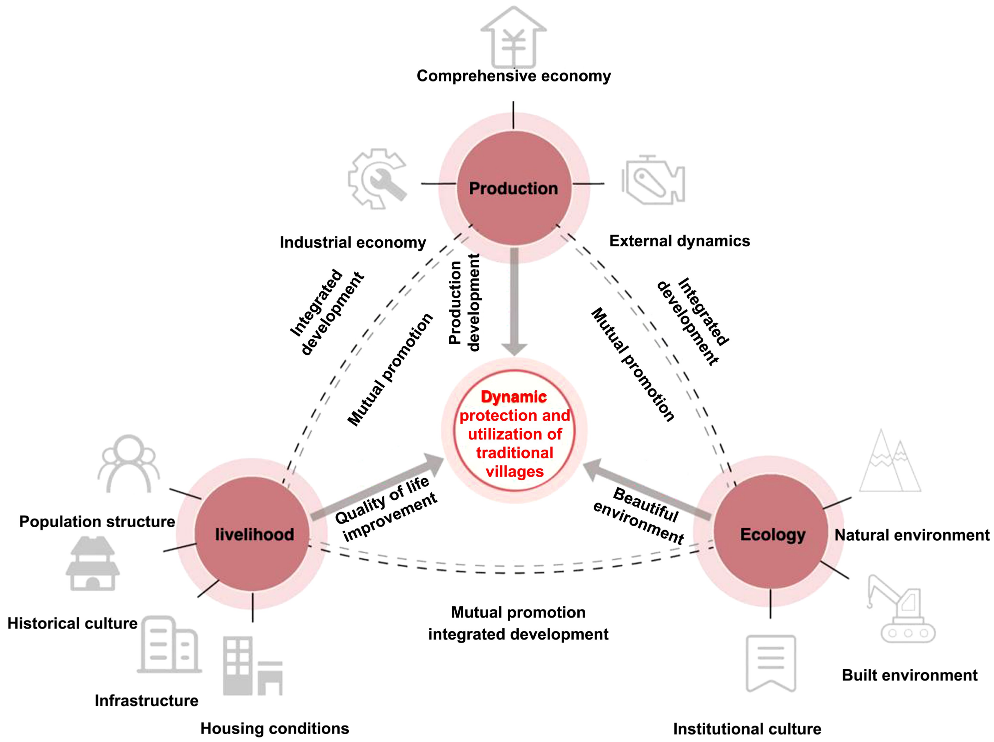

Figure 1 Integration of "three factors" and dynamic protection and utilization of traditional villages

1.2 Connotation of dynamic conservation and utilization of traditional villages

The conservation and utilization of traditional villages have long been a focal point in the field of architecture. In international theoretical research, notable achievements include "development anthropology theory" [13] and "heritage dynamics theory" [14]. In terms of technical methods, representative accomplishments primarily consist of "progressive small-scale renewal" [15] and a "socially driven conservation and utilization model" [16]. At the architectural level, the concept of Adaptive Reuse was formally introduced in the 1979 Venice Charter, defining it as "finding appropriate uses for heritage buildings (i.e., accommodating new functions) to ensure the maximum transmission and representation of the cultural value of the place while minimizing changes to the essential structure of the building" [17]. Domestically, research in this area started relatively later, especially in the realm of traditional villages. In recent years, most studies have been based on a cognitive theory of objective existence and static conservation, which has to some extent led to a lack of vitality in traditional villages and issues concerning the inhabitants' sense of belonging. In 2017, academician Wang Jianguo and others proposed that architectural cultural heritage is not a static "frozen" entity but advocates for a dual emphasis on the diversity of heritage conservation and creation [18]. In 2018, the country introduced the strategy of rural revitalization. In this context, the relevant theoretical research and model framework of rural construction need to move away from the original "static" research perspective and conservation model towards a comprehensive and dynamic understanding viewpoint.They are ultimately, approaching the issues of traditional village conservation and development from the perspective of "dynamic vitality" [19-22].

Based on the preliminary research analysis, the dynamic protection and utilization described in this paper embody a systematically ordered spatial dimension of integrated protection and a coordinated development of the temporal dimension as a holistic system. This approach

emphasizes not only the holistic protection of the material space of traditional villages from the perspective of the integration of "three factors" but also focuses on the dynamic inheritance of intangible culture over time and the coordinated development of traditional villages. The goal is to foster mutual enhancement between the conservation and utilization of traditional villages and the daily lives of villagers, enhancing their sense of happiness and achievement, thereby achieving sustainable development of traditional village development (Figure 2).

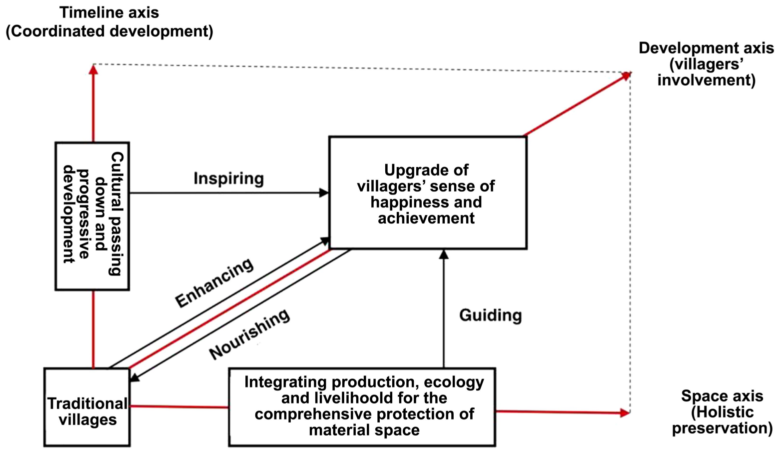

Figure 2 Implications of dynamic preservation of traditional villages

2 Traditional village dynamic protection and utilization: constructing diverse paths

2.1 Traditional village research and data analysis

The research team conducted four intensive surveys on traditional villages in various regions of China through a combination of online and offline methods focusing on the aspects of "production," "ecology," and "living." The online research primarily involved a literature review and case studies, while the offline surveys covered a total of 47 national and provincial-level traditional villages across the country, conducted in four phases. The first phase encompassed 22 national and provincial-level traditional villages in East, Central, South, and Southwest China. The second phase involved detailed research on five national-level traditional villages in Guizhou. The third phase focused on in-depth studies of 17 national and provincial-level traditional villages in the Jiangsu-Zhejiang region around Lake Taihu, with ten of these villages also being recognized as national and provincial-level historic and cultural villages. The fourth phase centered on studying three national-level traditional villages in Shiqian County, Guizhou, totaling over 1,000 collected documents.

During the research, the research team, based on significant differences in traditional culture, geographical environment, and socio-economic factors across different regions, conducted surveys on villages with different levels, types, heritage conditions, and development potentials. They utilized a combination of literature review, on-site surveys and measurements, and acquisition of data from multiple sources to review the current research systems and achievements, and collect relevant data. During on-site surveys and measurements, various data were extensively collected through field surveys, detailed building surveys, village committee investigations, questionnaire completion, and interviews with villagers. A database was established and data analysis was conducted (Table 1).

Taking the Lake Taihu region as an example, from the perspective of the "Three Factors", the analysis of research data from 17 national and provincial-level traditional villages revealed that the most distinctive features of the material space in traditional villages often exist in three tiers(as shown in the red frame): First, villages with unique overall layouts and intact preservation, such as Yigao Village in Huzhou, Zhejiang, and Luxiang Ancient Village in Suzhou, Jiangsu, where the surrounding natural landscapes exhibit typical characteristics of the Jiangnan water town, forming a distinctive overall layout closely integrated with the village and natural surroundings. Second, villages with high-quality historical buildings in well-pre-

served conditions, such as the "Three Famous Halls", including "Renben Hall (provincial-level cultural preservation, abbreviated as Provincial Preservation)," Xinyuan Hall (city-level cultural preservation, abbreviated as City Preservation), and Rongde Hall (city-level controlled preservation, abbreviated as City Controlled Preservation), in Tangli Village, Suzhou, constitute the most prominent feature of the village. Luxiang Ancient Village in Suzhou not only maintains an intact overall layout but also stands out as one of the highest-quality, most abundant, and best-preserved ancient village clusters in the Jiangnan region, with notable features like the Ming Dynasty old street in the village - Zishi Street, and famous buildings such as Huihe Hall (Wang Ao's former residence, Provincial Preservation), Suigao Hall (Provincial Preservation), Qianhe Hall (City Controlled Preservation), and Cuihe Hall (City Controlled Preservation). Third, the interior environments of buildings and construction techniques align with local climate characteristics, lifestyle, building technologies, and material forms, demonstrating highly effective and unique practices. Therefore, in constructing diverse paths for dynamic protection and utilization, targeted studies will be initiated based on the most distinctive features of traditional villages in terms of "overall village layout, individual buildings, and interior environments" derived from the research analysis.

Table 1 Sample data compilation form for traditional village survey

The Names of Villages	Geographical Locations	Classification	Grades	Production Status				Living Conditions					Ecological Status		Architectural Features		
				Population:	Income:	Per capita income	Featured Industries:	Completeness of Human Settlement Environmental Facilities	Transportation	Living Facilities	Featured Culture	Vitality	Natural Landscape Environment:	Village Spatial Environment:	Overall Layout	Historic Buildings	Interior Environment and Construction Techniques
Zhou Tie Traditional Village	Yixing City, Jiangsu Province	Plain water network type	Provincial-level traditional villages (National-level historical and cultural towns)	4584 individuals		Approximately 13,000 RMB	Well-developed featured industries in celery, lotus root, grapes, nursery planting, aquaculture	General Completeness	Convenient	Complete basic infrastructure, in good construction condition.	The leading town in Taihu Lake flood prevention; a millennium-old port and commercial port; a well-known cultural and educational area in the southeast.	Lack of vitality and vigor	The natural landscape environment features are excellent.	The village spatial environment features are excellent. The grid layout of the cross streets is well maintained.	√	√	
Luxiang Ancient Village	Wuzhong District, Suzhou, Jiangsu Province	Plain water network type	National-level traditional villages (National-level historical and cultural villages)	4710 individuals	Exceeding 5 million RMB solely from tourism	Exceeding 15,000 RMB	Well-developed featured industries primarily in tourism and cultural industries, with Su embroidery, tea, loquat, citrus fruits, and other agricultural products as highlights.	High Completeness	Relatively convenient	Complete living infrastructure.	The village hosts a rich cultural life.	Relatively high village vitality	The natural landscape environment features are excellent, surrounded by mountains on three sides, and located by the lake.	The village spatial environment features are excellent, with well-preserved traditional layouts, retaining the overall pattern of 'one street, six lanes, three rivers.'	√	√	√
Tangli Village	Wuzhong District, Suzhou, Jiangsu Province	Mountain resource type	National-level traditional villages	538 individuals	--	--	Well-developed featured industries primarily in agriculture and tourism, with the tertiary industry still in its initial stages.	Relatively High Completeness	Relatively convenient	Relatively complete living infrastructure.	--	Moderate village vitality	The natural landscape environment features are excellent, with a backdrop of mountains and facing the lake, nestled between mountains and waters.	The village spatial environment features are excellent, and the traditional layout of 'streets and lanes' is quite clear.		√	√
Yangfeng Village	Changxing County, Huzhou City	Mountain resource type	National-level traditional villages	1453 individuals	Exceeding 1.2 million RMB	Exceeding 30,000 RMB	Well-developed industries focusing on forestry, mineral resource development, and tourism, with a thriving tourism homestay industry.	High Completeness	Very convenient	Complete infrastructure, but lacking a clinic, villagers need to go outside the village for medical treatment.	Red Culture of the New Fourth Army	Insufficient vitality, with few young people returning, but with a significant number of tourists.	The natural landscape environment features are excellent, with forest coverage reaching 80%.	The village spatial environment features are excellent, with the most complete and largest preserved Revolutionary Old Site Group of the Suzhe Military Region, known as the 'Little Yan'an of Jiangnan.'		√	√

2.2 Construction of diverse paths for dynamic conservation and utilization of traditional villages

Based on the aforementioned field research and data analysis, a diverse path for dynamic conservation and utilization of traditional villages has been constructed, combining multi-level paths in the spatial dimension and time-based paths in the temporal dimension, as illustrated in Figure 3. The multi-level paths correspond to the holistic protection of the spatial axis within the overall system of dynamic protection and utilization, addressing the optimization of material space, initiating the dynamic protection process of traditional villages, and systematically constructing corresponding paths and methods starting from the three tiers of "overall village layout, individual buildings, and interior environments." The time-based paths correspond to the coordinated development along the temporal axis within the overall system of dynamic protection and utilization, addressing the complex social and economic factors involved in dynamic protection and utilization of traditional villages. They are gradually implemented in stages according to short-term, medium-term, and long-term phased strategies, followed by empirical application in demonstration projects, summarizing and optimizing the diverse paths.

2.3 Multi-level paths

The multi-level paths primarily focus on the optimization of material space, with each of the three tiers of "overall village layout, individual buildings, and interior en-

vironments" emphasizing different aspects while interweaving with each other. This approach can effectively improve people's living and working conditions, enhance the attractiveness of traditional villages, provide a platform for the development of industrial economy and social culture, and thereby offer intrinsic dynamics for the long-term development of traditional villages, to address some extent the problem of traditional village hollowing.

(1) Overall village layout level

At the level of the overall village layout, government and professional organizations play a leading role. Comprehensive consideration is given to the external landscape characteristics of the village, conducting in-depth research and analysis on elements such as the mountain-and-water layout, general appearance, public spaces, transportation and infrastructure, and industrial conditions. This informs a comprehensive positioning for the dynamic protection and utilization of traditional villages, determining an overall development strategy in conjunction with phased temporal paths for the short-term, medium-term, and long-term.

Building upon the overall positioning, it is essential to conduct in-depth research and quantitative analysis of elements such as spatial structure, public spaces, resident behaviors, infrastructure, and building conditions at the holistic level of traditional villages. This will lead to the formulation of specialized guidelines for village environment, public spaces, infrastructure, building renewal, industrial planning, public services, etc., providing scientific guidance for the construction of subsequent projects.

(2) Individual building level

The advancement of the individual building level typically occurs in the form of spontaneous micro-updates driven by residents, guided by the government and professionals. It consists of two aspects: Firstly, based on preliminary research, a comprehensive evaluation of individual buildings is conducted to develop appropriate preservation and utilization strategies, in line with temporal paths to determine specific contents at each stage. Through the analysis and quantification of factors such as the building's preservation level, historical value, architectural craftsmanship, relationship with the environment, existing conditions, and value for preservation and utilization, diverse strategies including prioritizing protection, inheritance, and development are formed based on quantitative evaluations to guide renovation measures for different types of individual buildings.

Secondly, through building surveys, mapping, and typological organization, a database is established containing key information on building structural forms, functional spaces, architectural facades, and traditional craftsmanship components. Targeted guidance is provided for protection and renovation at the individual building level. Through demonstration projects, systematic enhancements are implemented for individual buildings to integrate spatial and physical performance, better serving the current needs of villagers.

(3) Interior environment level

The interior environment is closely linked to residents' lives, directly addressing the need for cultural heritage continuation and improvement of living conditions for villagers. Typically, residents voluntarily undertake updates in compliance with guidelines and regulations at the village and individual building levels, often in the form of micro-updates. Addressing residents' needs for health, comfort, safety, durability, and facility improvements, the dynamic protection and utilization of the interior environment level progresses through a combination of short-term, medium-term, and long-term measures. This gradually establishes a beneficial cycle of traditional aesthetics continuation and improvement in residents' living environments.

2.4 Temporal paths

Temporal paths correspond to the coordinated development along the time axis within the overall system of dynamic protection and utilization, aimed at addressing the complexity and contradictions inherent in the dynamic protection and utilization of traditional villages. They are implemented gradually in stages combining short-term, medium-term, and long-term strategies. Temporal paths intertwine and cooperate with multi-level paths to achieve incremental updates and long-term development of traditional villages.

Whether at the village level, individual building level,

or interior environment level, the short-term path primarily focuses on remedial enhancements based on current village development and residents' living conditions to meet present-day needs, thereby initiating the path to dynamic revitalization. The medium-term path involves a relatively comprehensive enhancement of material spatial environments, incorporating elements of cultural heritage to promote mutual growth and development of traditional village material space and cultural heritage. The long-term path embodies the ideal state where material space is comprehensively optimized, and cultural heritage and material space development complement each other.

From the perspective of integrating the "three factors," optimizing the material space within the "livelihood" context can initiate the dynamic development of traditional villages. This can effectively facilitate further integration and enhancement of "production" and "ecology" aspects. For instance, fostering the development of rural tourism not only boosts tourism-related handicrafts, agriculture, manufacturing, and services but also promotes the convergence of rural primary, secondary, and tertiary industries into a foundational "mega-industry." Additionally, rural residents can benefit economically and culturally from the development of rural tourism, encouraging them to actively improve the material spatial environment of villages, and unearth and preserve cultural heritage, thereby achieving the sustainable development of traditional villages [24,25].

3 Practice and application of dynamic preservation and utilization of traditional villages around the Lake Taihu region

3.1 Characteristics, issues, and selection of typical cases of traditional villages in the Lake Taihu region

The Lake Taihu region typically refers to the area centered around Suzhou and includes Wuxi, and Changzhou, as well as counties such as Wujiang, Yixing, Changshu, Kunshan, and Taicang [23]. This region boasts excellent natural conditions and has historically been one of the most prosperous areas in China. The historical and cultural standards of traditional architecture in the Lake Taihu region are outstanding [26], with a significant number of national and provincial-level traditional villages still preserved in the region, characterized by relatively well-preserved traditional residential buildings (Figure 4). However, traditional villages in the Lake Taihu region also face challenges such as poor infrastructure, aging and dilapidated housing, and unfavorable living environments. Additionally, the lack of industrial development momentum and the migration of many young people to urban areas has exacerbated the issues of aging and hollowing out of traditional villages, making the task of dynamic protection and utilization urgent.

Building upon the extensive longitudinal research conducted by the research team, an empirical study was carried out on the application of diverse paths for dynamic protection and utilization using Zhoutie traditional village as an example. Zhoutie traditional village is the oldest part of Zhoutie Ancient Town (a nationally recognized historic and cultural town) and has developed a spatial layout centered around the Cross River and Cross Street during its long history (Figure 4). The preservation of buildings in Zhoutie traditional village is relatively good, with two city-level protected buildings, one controlled preservation unit, and 76 historical buildings. The natural environment, spatial layout, development history, and challenges faced by Zhoutie traditional village are broadly representative of the Lake Taihu region (highlighted in the blue box in Table 1). In recent years, driven by major development projects such as the Phase 2 project of Nianhua Bay and the Submarine Tunnel under Lake Taihu, Zhoutie has witnessed significant opportunities for dynamic protection and utilization.

3.2 Overall positioning of dynamic protection for village at the level of the whole village

Based on extensive prior research and data analysis, the research team comprehensively reviewed the production, living, and ecological elements of Zhoutie traditional village (including geographical location, overall layout, village history, folklore, architectural style, public spaces, transportation systems, infrastructure, and industrial conditions). A comprehensive assessment of the current protection and utilization status was conducted. Building upon this foundation and in conjunction with government development plans, a comprehensive study of the overall strate-

gy and methods for dynamic protection and utilization of Zhoutie traditional village was carried out. The overall positioning for dynamic protection and utilization was established, focusing on maintaining a primarily residential functional structure while developing commercial, cultural industries, and tourism based on the inheritance and promotion of material and cultural heritage. The aim is to gradually restore Zhoutie as a complex entity integrating residential, commercial, and cultural entertainment activities. A phased and staggered implementation path combining short-term, medium-term, and long-term goals was proposed (Figure 5) to provide comprehensive guidance for the dynamic protection and utilization of Zhoutie traditional village.

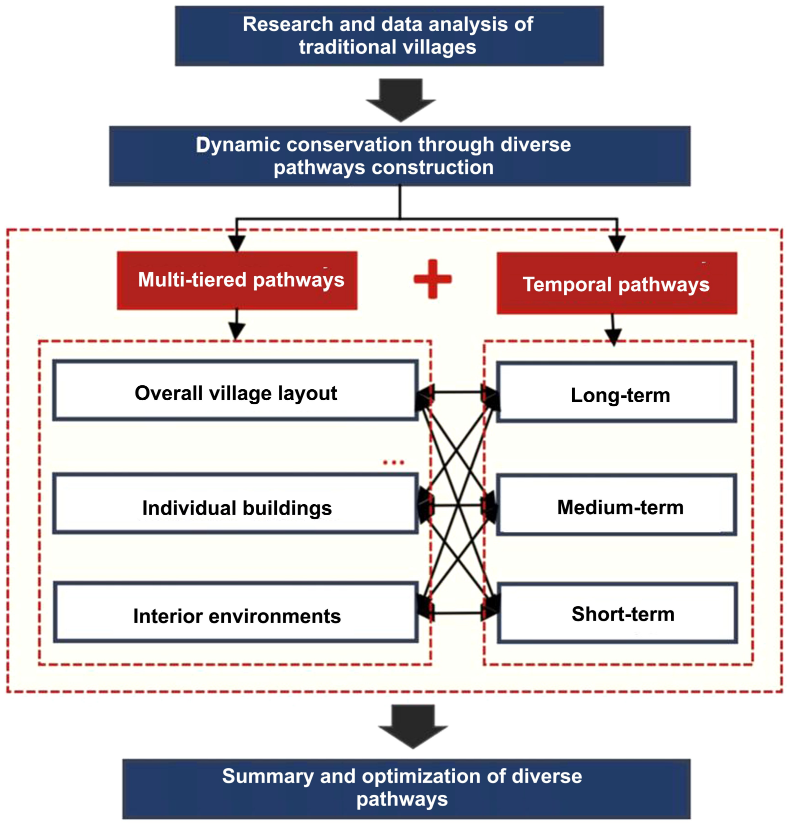

Figure 3 Steps and contents of constructing multi-tiered and diverse pathways in traditional villages

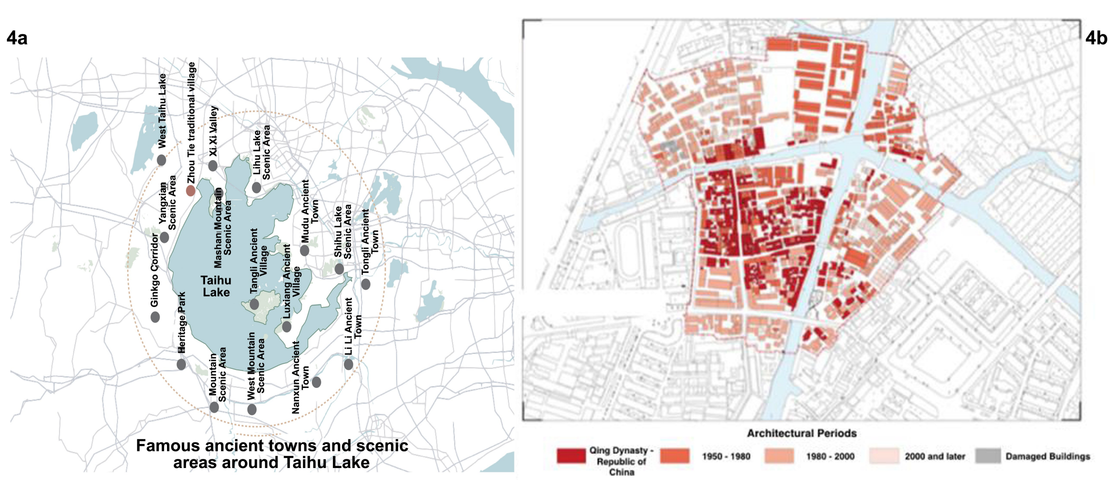

Figure 4a Distribution of famous ancient towns and scenic areas around Lake Taihu region, with the location of Zhoutie traditional village

Figure 4b Overall layout of Zhoutie ancient village

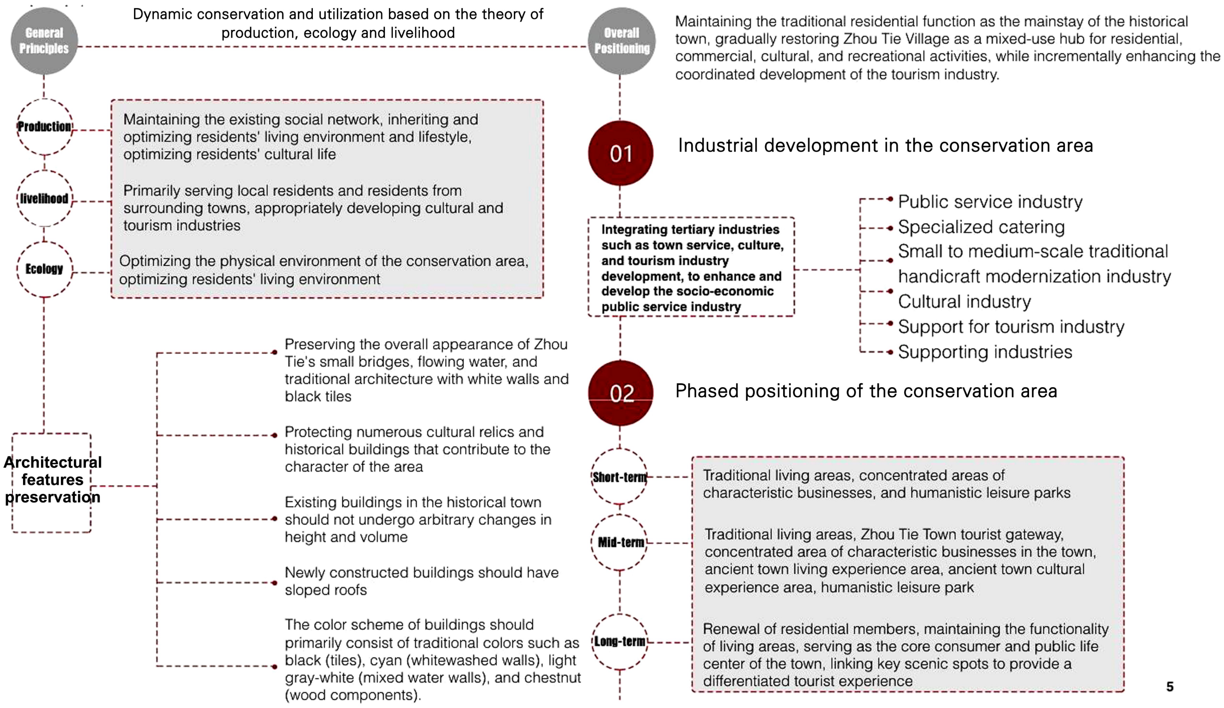

Figure 5 General positioning framework for the dynamic conservation and utilization of Zhoutie traditional village

Building on this overall positioning, specific research and guidelines were developed for the public spaces of Zhoutie traditional village, focusing on the most critical areas in the village spatial layout, such as the north-south streets, east-west streets, and the riverside space along the Cross River, outlining corresponding dynamic positioning and protection and utilization guidelines (Figure 6).

3.3 Diverse strategies at the individual building level

Taking into account the protection level, architectural value, existing conditions, and potential value for dynamic utilization of current buildings in Zhoutie, a hierarchical classification mechanism was proposed for buildings. The

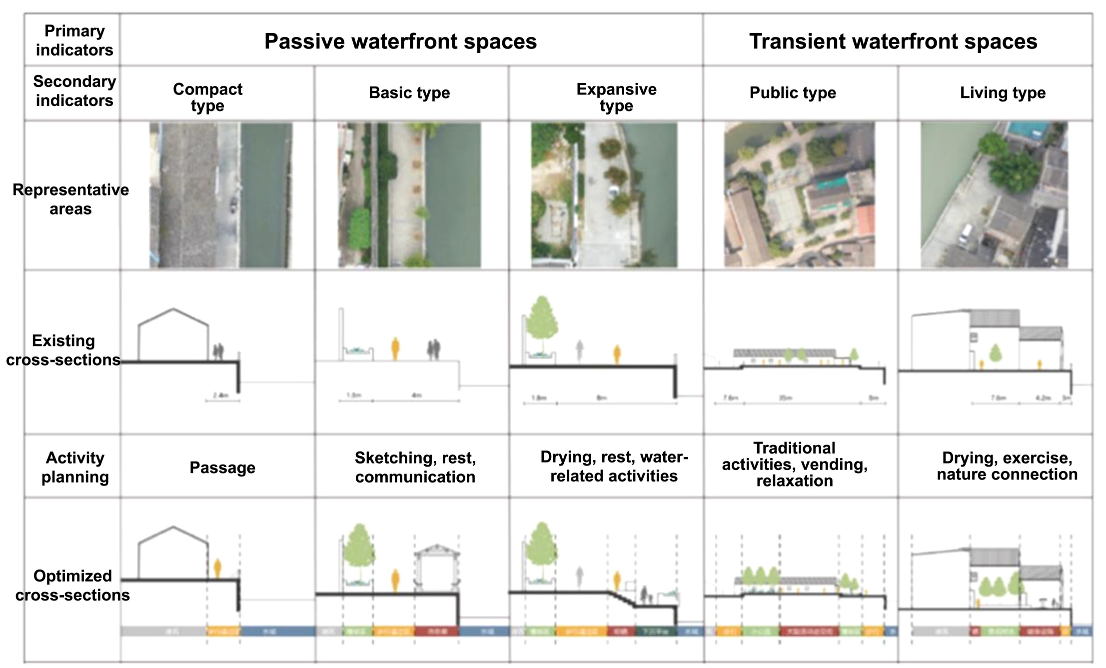

Figure 6 Formulation of special guidelines: dynamic design guidelines for waterfront spaces along the cross river

Analytic Hierarchy Process (AHP) method was employed to evaluate individual buildings. Expert assessments determined the weights of four criteria as follows: historical value (38.74%), architectural art and construction technology (16.53%), architectural environmental relevance (17.02%), and existing conditions with potential for dynamic utilization (27.71%). Ratings were assigned to each building based on the four criteria, and weighted calculations were performed to establish a score for each building. This resulted in a classification of buildings into protected, heritage, and development categories. Diverse protection strategies were tailored for each building type, specifying corresponding utilization guidelines to offer guidance for the dynamic protection and utilization of the various building types (Figure 7). Through comparison and validation with on-site building preservation and utilization cases, it was found that the completed building preservation and utilization cases corresponded well with the protection types and strategies identified by the classification assessment system. Therefore, the evaluation system will be used to guide future demonstration projects and other preservation and utilization practices in the village.

(1) Protected buildings (comprehensive assessment score > 75 points): corresponding to the 2 municipally protected buildings within the village and historic buildings with high evaluation scores. These structures are typically preserved intact according to relevant laws and regulations, with documentation established, listings made public, and their reuse usually government-led. The transformed Zhuxi Academy, depicted in the left image in Figure 7, serves as a typical example of a protective building with a preservation and utilization method led by the government.

(2) Heritage buildings (comprehensive assessment score 50-75 points): corresponding to the majority of the 76 historic buildings within the village. Planning control management is implemented, encouraging protection and reuse under modern needs while preserving the architectural style of protected buildings. Methods such as retention or partial retention are often employed to maintain the architectural character. The facade transformation and spatial updates of street-facing buildings completed under governmental guidance, as shown in Figure 7, mostly fall under this category.

(3) Development buildings (comprehensive assessment score < 50 points): corresponding to the numerous non-protected and non-historic buildings within the village. These buildings can undergo significant redesign and updates without compromising the overall village aesthetics. For instance, the transformation of a village residential building into a commercial structure completed voluntarily by villagers, as shown on the right in Figure 7, is typically led by the villagers themselves with the government providing necessary guidance and assistance.

As one of the demonstration projects of the research topic, the former supply and marketing cooperative located at the intersection of the southern end of North-South Street and Xueqian Road has been transformed into a new Party and Mass Service Center (village committee), doubling as a comprehensive tourism information center, making it a typical case of development-oriented architectural preservation and reuse. Analyzing from the perspective of diversified path construction, the building transformation aligns with the mid-term renovation path at the individual building level. This public building, dating back to the 1980s, was originally used as a supply and marketing cooperative. During the renovation process, the original spatial layout of the building was largely preserved, the building structure was renovated and strengthened, materials and structures were upgraded, the spatial configuration was improved, auxiliary spaces such as restrooms and storage rooms were introduced, and building equipment was updated. After the transformation, it became a shared space for villagers and tourists, serving multiple purposes including Party and Mass Service Center, village committee, and tourist service center. The research team assisted local authorities and design units in optimizing the street-facing facade design. The original facade form of the building was largely preserved, retaining its original characteristics, while contemporary materials such as stainless steel and wood were introduced at the ground level. This not only provided seating for villagers and tourists to rest and interact but also highlighted the public nature of the building and its contemporary features (Figure 8).

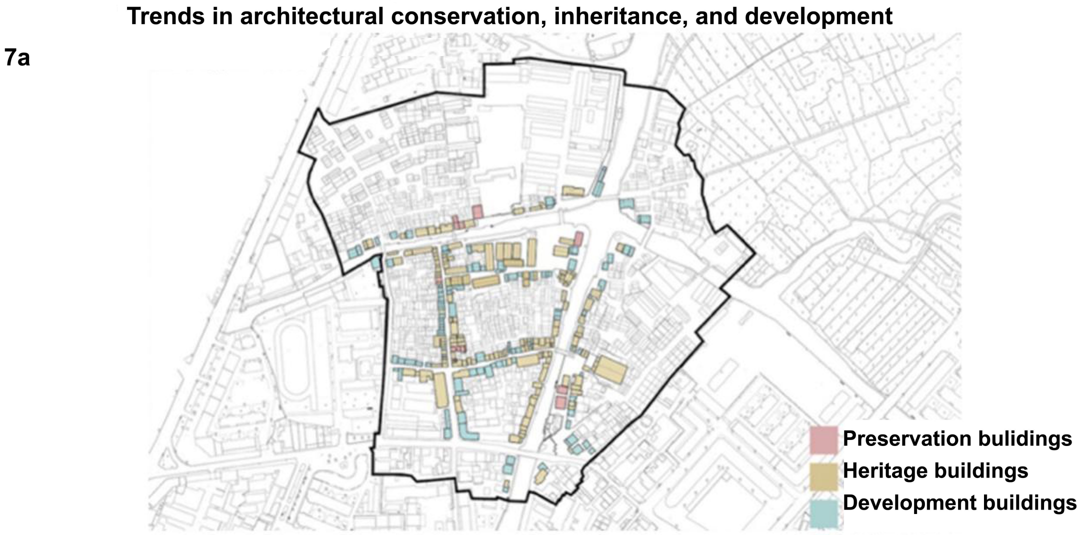

Figure 7a Preservation and utilization strategies for street-side buildings in Zhoutie traditional village

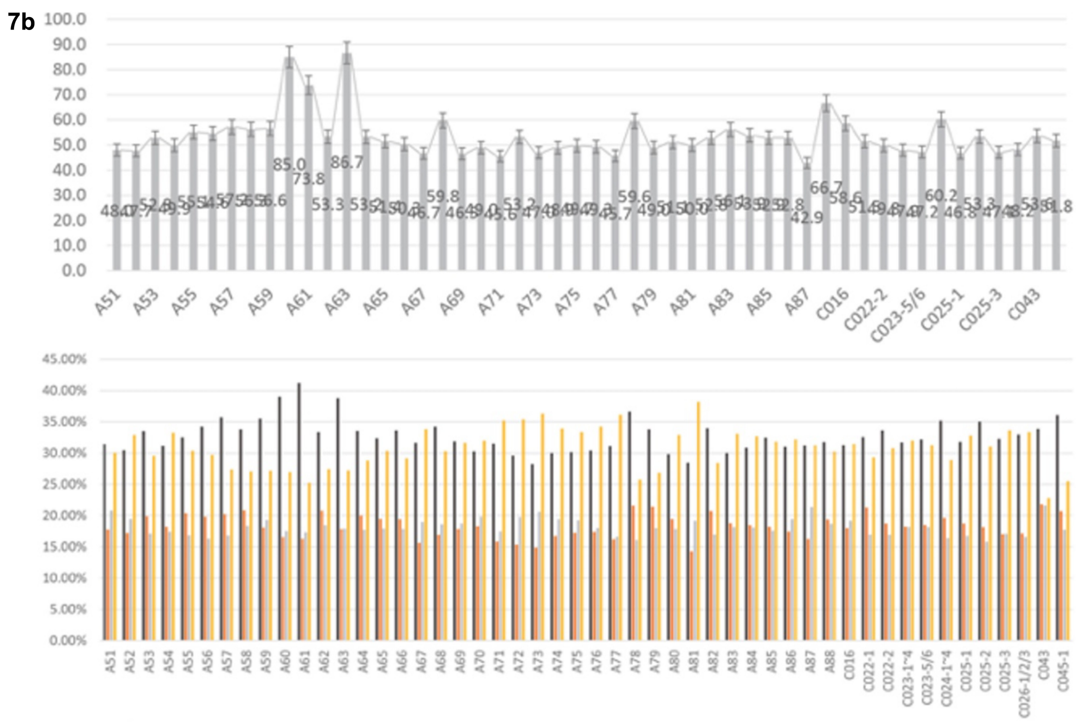

Figure 7b Building score distribution based on the village architectural evaluation system (upper: total score, lower: secondary indicator scores)

3.4 Integrated enhancement of spatial performance and physical performance at the interior environment level

The interior environment level is closely related to residents' lives and is often completed by residents in a self-improvement manner based on relevant regulations, although some public housing renovations require government leadership. During the preliminary research, it was found that the residential buildings in Zhoutie traditional village commonly suffer from issues such as narrow indoor spaces, poor physical environments in terms of lighting and ventilation, and inadequate facilities, which do not meet the requirements of contemporary living. Taking the residential building shown in the left image of Figure 9 as an example, measurements indicated that the maximum daytime illuminance in the bedroom was only 20lx, whereas according to the current national residential lighting standards, the standard value for bedroom lighting should

be between 75-100lx. Therefore, the primary task in the dynamic protection and utilization of the interior environment level is to improve the living conditions by integrating space design and updating facilities to achieve an integrated enhancement of interior spatial performance and physical performance.

Figure 7c Preservation and utilization of historic building: Zhuxi academy

Figure 7d Heritage buildings: transformation of street-side residential spaces and facades

Figure 7 Development buildings: transformation of village residential buildings into commercial buildings

Figure 8a Zhoutie village community center after renovation

Figure 8b partial facade of Zhoutie village community center after renovation

In the dynamic protection and utilization of the interior environment level, a progressive approach combining short-term, medium-term, and long-term strategies should be adopted, with specific practices as follows:

(1) Short-term preliminary enhancement: primarily serving the current needs of residents, initial enhancements are carried out with temporary remedial measures while attempting to preserve the original spaces and structures. This phase involves simple content, limited investment, but relatively short effectiveness. Key elements include building repairs and structural reinforcements, initial enhancement of building physical performance, optimization of lighting and ventilation design, and appropriate equipment updates.

(2) Medium-term comprehensive enhancement: a relatively comprehensive upgrade carried out while maintaining the current functionality and spatial layout of the building. This phase includes upgrading the materials and structures of the existing building, refining the living space configuration, introducing auxiliary spaces such as kitchen and bathroom storage, initial enhancement of building physical performance, and updating building equipment.

(3) Long-term comprehensive enhancement: considering the future development of the building while preserving its architectural character, a comprehensive improvement of the internal space is undertaken to meet contemporary functions and usage requirements. This phase involves optimizing interior space performance, integrating internal spaces to meet new life needs, enhancing the physical performance of the indoor environment by optimizing lighting and ventilation design and improving the building envelope structure, optimizing functional spaces such as kitchen, bathroom, and storage, and appropriately adding new equipment and facilities.

The case shown in the right image of Figure 9 is a government-led renovation of a dilapidated building located on the north side of North-South Street. Originally a residential building and categorized as public housing, the structure was on the brink of collapse due to long-term neglect. The government conducted a comprehensive long-term upgrade, transforming it from a purely residential function to a mixed-

use development combining commercial and residential purposes. During the preservation and renovation process, the original facade of the residential building was retained, the existing structure was reinforced and repaired, and comprehensive transformations and upgrades were implemented for the spatial layout, functional configuration, physical performance, and facilities of the building. Following the renovation, significant improvements were achieved in the indoor lighting performance. Near window areas experienced a maximum illuminance of 150lx, with an average illuminance of 59lx throughout the indoor spaces, aligning closely with the current national residential lighting standards. The comfort and usability of the interior spaces have significantly improved, better meeting contemporary comfort standards. The building is currently leased to and operated by a teahouse, demonstrating successful dynamic protection and utilization.

9a

9b

Figure 9a Typical interior conditions of residential buildings in Zhoutie village

Figure 9b Comprehensive renovation of residential buildings (converted into a tea house) after renovation

4 Conclusion and discussion

Based on previous research and demonstration projects, this paper, starting from the perspective of the integration of "Three Factors," constructs a diverse path of dynamic protection and utilization that combines multilevel paths in spatial dimensions and duration paths in temporal dimensions. Taking the traditional village of Zhoutie in the surrounding area of Lake Taihu as an example, this paper elaborates on the practical application of the diverse paths and draws the following conclusions:

(1) Through the lens of the "Three Factors" integration, starting from a holistic and systematic perspective, it is recognized that there is a comprehensive and dynamic relationship between the three key factors influencing the formation and development of traditional villages - industrial status (production), regional natural resources (ecology), and historical, cultural, and residential conditions (livelihood) - and dynamic protection and utilization. This relationship helps in harmonizing industrial development, improving residents' living environment, and enhancing ecological environment construction, allowing traditional villages to gain sustainable endogenous dynamics.

(2) This study reveals that dynamic protection and utilization manifest as a systematically ordered spatial dimension of integrated protection and coordinated development in the temporal dimension as a holistic system. It emphasizes not only the overall protection of the material space of traditional villages but also the collaborative development of intangible culture and traditional villages in the temporal dimension. The goal is to promote mutual enhancement between the conservation and utilization of traditional villages and the daily lives of villagers, enhancing villagers' sense of happiness and achievement, thereby achieving sustainable development of traditional villages.

(3) The paper constructs a diverse path that integrates spatial and temporal dimensions for the dynamic protection and utilization of traditional villages. This path spans multilevel paths covering the overall village, individual buildings, and indoor environments in the spatial dimension, and a duration path combining short-term, medium-term, and long-term perspectives in the temporal dimen-

sion. These dimensions intertwine and promote each other, collectively advancing the holistic dynamic protection and utilization of traditional villages. Through the optimization and summary of demonstration projects, forward-looking and practical ideas are proposed.

The research on the multi-path construction of traditional villages in terms of temporal and spatial dimensions in this paper, along with the detailed explanation using the traditional village of Zhoutie in the surrounding area of Lake Taihu as an example, will contribute positively to the development of an integrated and dynamic "dynamic" conservation and utilization mode for traditional villages in various regions of China, promoting the sustainable development of traditional villages.

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Analysis of Urban Thermal Environment Improved by Blue-Green Spaces on the Landsat Data: A Case Study on Tianjin

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ABSTRACT: China's urbanization is characterized by rapid speed, large scale and high energy consumption, which causes a series of ecological problems. Among these problems, urban thermal environment is particularly prominent, and the most intuitive reflection is the heat island effect. It is of great significance to optimize the urban layout to give full play to the cooling effect of blue-green spaces for improving urban thermal environment. Compared with other methods, it is more extensive and feasible. However, the current research on urban thermal environment mostly focuses on revealing the driving effects of different land use, and lacks of in-depth discussions on blue-green spaces. Tianjin is located in the northeast of the North China Plain, and has a typical warm temperate sub-humid monsoon climate. This paper takes the six districts of Tianjin City as the research area, covering Heping District, Nankai District, Hongqiao District, Hebei District, Hexi District and Hedong District, with a total area of about 181.18 square kilometers. The typical climate and urbanization characteristics of Tianjin can provide reference for cities with the same characteristics. Firstly, this paper had adopted the Landsat changing scenario of the city gained during the periods of 2004, 2011 and 2017 to formulate the land surface temperature by Mono-window Algorithm, and divided the results into seven temperature zones by standard deviation classification method. In regard to blue-green spaces, this paper had identified Landsat satellite data by Maximum Likelihood Classifier, and classified land use into three categories: blue spaces, green spaces, and non-blue and green spaces. And, next, this paper had studied the correlation between the landscape pattern of blue-green spaces and urban thermal environment by Landscape Pattern Analysis, and used Moving-window Analysis to compare the relationship between thermal environment and blue-green spaces at different spatial scales. And so the research results prove that, the high-temperature regions of Tianjin has been expanding along with the expansion and agglomeration of the urban areas and across the river space restrictions, while the low-temperature regions of the city are mainly concentrated in the blue-green spaces, during the periods of 2004, 2011 and 2017. Furthermore, in the landscape pattern level, there is a significant negative correlation between patch perimeter index of blue-green spaces and land surface temperature, and a significant positive correlation between patch perimeter area ratio index of blue-green spaces and land surface temperature. In the multi-scale spatial pattern, the correlation between the Percent of Landscape of blue spaces patches and land surface temperature is the highest in the 1500 meters × 1500 meters sample, and the Percent of Landscape of green spaces patches and land surface temperature is the highest in the 300 meters × 300 meters sample. In addition, the improvement efficiency of thermal environment in blue spaces is higher. In the end, the optimization suggestions of adjusting the layout of blue-green spaces to effectively improve the urban thermal environment problem are proposed. By optimizing the blue-green space landscape patterns at the optimal scale, increasing the blue spaces in the northern high temperature range, widening and transforming the existing waterways, constructing riverside greenways and other strategies to effectively deal with the thermal environmental

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problems, improving the ecology and livability of the city. It is hoped to provide new ideas and references for the construction of ecological and livable city under the background of rapid urbanization. In the research process, due to the limitation of data sources, calculation methods and other factors, the relevant conclusion is still limited at the spatial scale. In the future research, the thermal environment and the pattern of blue-green spatial landscape at the fine scale will be studied.

KEY WORDS: *blue-green spaces; urban thermal environment; land surface temperature; landscape pattern*

Introduction

Cities, the vast carriers intricately intertwined with politics, economy, society, and culture, are human constructs that have gradually become a historical trend in the process of human development. Urbanization in China is characterized by its rapid pace, large scale, and high resource consumption, which has exacerbated a series of ecological problems with thermal environment issues being particularly prominent, manifested most strikingly in the urban heat island effect. The primary causes contributing to thermal environment issues can be attributed to two main factors: urbanization-induced landscape pattern evolution and alterations in the balance between urban surface energy and radiation due to changes in human production and lifestyle [1,2]. Currently, measures that can effectively ameliorate thermal environment issues can be broadly categorized into the following three types: (1) reducing anthropogenic heat sources by limiting motor vehicle travel and decreasing the usage frequency of air-conditioners; (2) enhancing infrastructure materials such as constructing reflective roofs or high-ratio heat capacity roads; (3) optimizing urban layout, for example, increasing the underlying surface of landscape, planning transportation in accordance with the prevailing summer wind direction [3-5]. However, improving infrastructure materials may pose high costs for many developing countries and regions. Hence, apart from minimizing anthropogenic heat sources, a more widely applicable and feasible approach lies in strategic planning that leverages the cooling impacts of green spaces and water bodies [3,6].

Presently, there are three main research methods employed in studying urban thermal environment issues. The first method involves satellite remote sensing image analysis, focusing on a macro scale. It offers advantages such as broad coverage and strong dynamism, albeit susceptible to accuracy issues and computational errors. In 1972, Rao et al. [7] conducted the first study on the urban heat island effect using satellite thermal infrared remote sensing in the mid-western coastal cities of the United States, paving the way for the widespread application of satellite remote sensing images. The second method is on-site observation and measurement, where early research data primarily originated from meteorological stations, similarly centered on a macro scale [8]. With the advancement of infrared thermometers, the "point method" was introduced, directing attention towards local microclimates; however, a significant drawback is the interchange of "point" observations for "area" outcomes. The third method involves computer simulation calculations, leaning towards a meso-micro scale range [9], offering highly visualized results but heavily reliant on external input data. With the enhancement in accuracy of satellite remote sensing image data, scholars have increasingly employed the first method for studying the patterns of urban thermal environment and landscape layout.

In the study of the regularities concerning urban thermal environment and landscape patterns, Singh Prafull et al.[10] creatively incorporated ecological assessments of blue-green spaces into thermal environment evaluations by analyzing surface temperature distribution characteristics in Lucknow of India over the past 12 years using Landsat data. This widened the perspective of thermal environment research and laid theoretical groundwork for the correlation between thermal environment and blue-green spaces. Ding Haiyong et al. [11], based on Landsat data from 2000 to 2015 in Nanjing, researched the evolution patterns of urban heat island effects and landscape layouts, pinpointing significant cooling effects of vegetation and water surfaces. Qin Menglin et al. [12] conducted a study on the

spatial evolution of heat islands in urban clusters from 2001 to 2015 using MODIS land surface temperature data, identifying wooded areas as stable cold spots within the city. Shen Zhongjian et al. [1], using Landsat as their data source, analyzed the spatiotemporal patterns of heat islands in Fujian delta urban agglomeration from 1996 to 2017, revealing wooded areas and water bodies as stable cold sources. Deng Yujiao et al. [13], based on remote sensing data from the Guangdong-Hong Kong-Macao Greater Bay Area from 2003 to 2018, analyzed the spatiotemporal distribution characteristics of urban heat islands and highlighted the significant impact of vegetation on heat islands. These studies demonstrate a systematic spatial relationship between urban thermal environment and land use, emphasizing the significant ameliorative effects of blue-green spaces such as green spaces and water bodies.

However, current research on urban thermal environments tends to focus on revealing the driving influences of different land use types, lacking in-depth exploration of blue-green spaces. This paper takes a blue-green spaces perspective, emphasizing the spatiotemporal evolution characteristics of urban thermal environments and blue-green spaces. It investigates the correlation between thermal environments and green spaces as well as water bodies at the landscape pattern level and across different spatial scales. Starting from blue-green spaces, spatial planning recommendations to improve the thermal environment are proposed.

1 Study area and data source

1.1 Study area

Tianjin is located in the northeast of the North China Plain, downstream of the Haihe River basin, and borders the Bohai Sea to the east. It is one of the core cities in the Beijing-Tianjin-Hebei urban agglomeration. The region has a typical warm temperate semi-humid continental monsoon climate, with hot summers and cold winters. As a sample of rapid urbanization in China, Tianjin's urban construction land area expanded from 371.23 square kilometers in 1998 to 950.55 square kilometers in 2018, bringing along serious heat environment issues. Currently, there is limited and insufficient research on the heat environment in the city, with even less related to blue-green spaces [14]. The "Tianjin Municipality's Fourteenth Five-Year Plan for National Economic and Social Development and Vision for 2035" explicitly emphasizes promoting green development and accelerating the construction of a beautiful Tianjin, with blue-green spaces being a key focus. Therefore, this study utilizes Landsat remote sensing image data and selects the core six districts in Tianjin's main urban area as the research focus to explore the relationship between the heat environment and blue-green spaces, including Heping District, Nankai District, Hongqiao District, Hebei District, Hexi District, and Hedong District, covering a total area of approximately 181.18 square kilometers (Figure 1). The typical climate characteristics and urbanization features of Tianjin can serve as reference for cities with similar characteristics.

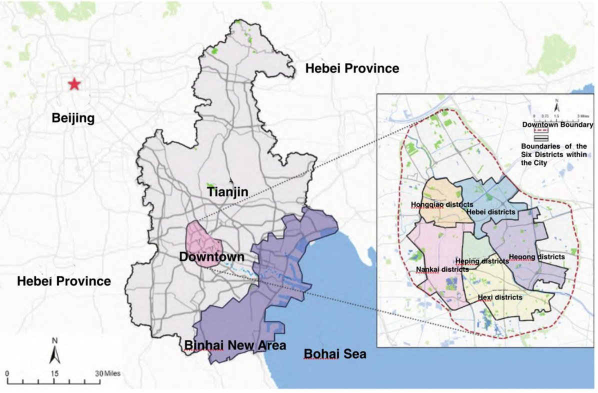

Figure 1 Study area

1.2 Data sources and preprocessing

Geospatial data from the Landsat remote sensing images, published on the Geospatial Data Cloud Platform (http://www.gscloud.cn/), were used as the data source for analyzing the urban heat environment and blue-green space patterns. The imaging dates were July 6, 2004, June 8, 2011, and July 10, 2017. The data source has a large time span which is conducive to studying spatial evolution characteristics, especially during which time the vegetation has a vigorous growth, as shown in detail in Table 1. The data source was processed using ENVI for multispectral radiometric calibration and atmospheric correction, and then was calibrated and clipped to obtain the preprocessed data results.

Table 1 Statistical information of data sources

Imaging time/ year-month-date	Satellite and sensor	Spatial resolution/m×m		Center longitude/ latitude/°	Strip number	Line number	Imaging beijing time	Cloud cover/%
		Thermal infrared band	Other bands					
2004-07-06	Landsat 5 TM	30	30	116.2725E 38.8988N	123	33	10:35:58	0.01
2011-06-08	Landsat 5 TM	30	30	116.242E 38.8995N	123	33	10:43:19	0.03
2017-07-10	Landsat 8 OLI_TIRS	30 (TIRS)	30 (Panchromatic15)	116.2848E 38.9042N	123	33	10:53:43	0.04

2 Research methodology

2.1 Land surface temperature inversion

The Mono-Window Algorithm with minimal errors was selected to invert the urban land surface temperature [15,16]. This algorithm is simpler and more convenient compared to the Radioactive Transfer Equation Method, Single-channel Method, and Image-based Method. Firstly, the average atmospheric action temperature (Ta) for Tianjin was obtained from the China Meteorological Yearbook. The atmospheric transmittance (τ) was calculated using the Atmospheric Correction Parameter Calculator from the official website of the National Aeronautics and Space Administration (http://atmcorr.gsfc.nasa.gov/). Subsequently, using ENVI, the pixel brightness temperature (T) of the thermal infrared band for each year was calculated, and the land surface emissivity (ε) was computed based on the NDVI thresholding method proposed by SobrinoJ et al. [17]. Finally, the land surface temperature in Kelvin (K) for each year was calculated using the Qin Zhihao Mono-Window Algorithm formula:

$$T_{s\_Qin}=\frac{a(1-C-D)+[b(1-C-D)+C+D]T-DT_a}{C} \quad (1)$$

In the equation, a and b are coefficients with values of a = −67.355 35 and b = 0.458 61 when within the range of 0 ℃ to 70 ℃. The calculation formula for C is C = τ×ε and for D is D= (1−τ)×[1+ τ×(1−ε)].

2.2 Temperature difference zoning

Applying the standard deviation classification method to differentiate surface temperature calculation results [14], and to compare and study the spatiotemporal evolution characteristics of the thermal environment in various years. The final zoning consists of 7 temperature ranges, with extremely low temperature zone, low temperature zone, and relatively low temperature zone representing the urban low-temperature range areas, while extremely high temperature zone, high temperature zone, and relatively high temperature zone representing the urban high-temperature range areas (Table 2).

Table 2 Ground surface temperature zone

	Temperature range/℃	Temperature zones
Low-temperature range area	$LST < T_{mean} - 2T_{std}$	Extremely low temperature zone
	$T_{mean} - 2T_{std} \leqslant LST < T_{mean} - T_{std}$	Low temperature zone
	$T_{mean} - T_{std} \leqslant LST < T_{mean} - 1/2T_{std}$	Relatively low temperature zone
Medium temperature range	$T_{mean} - 1/2T_{std} \leqslant LST < T_{mean} + 1/2T_{std}$	Medium temperature zone
High-temperature range area	$T_{mean} + 1/2T_{std} \leqslant LST < T_{mean} + T_{std}$	Relatively high temperature zone
	$T_{mean} + T_{std} \leqslant LST < T_{mean} + 2T_{std}$	High temperature zone
	$LST \geqslant T_{mean} + 2T_{std}$	Extremely high temperature zone

2.3 Land use classification interpretation

Utilizing the Maximum Likelihood Classifier in Supervised Classification to interpret land use classification from the data source, extracting 3 spatial patterns: blue

spaces, green spaces, and non-blue-green spaces, to analyze the relational characteristics among different elements within the landscape system. The blue spaces include natural and artificial water bodies, the green spaces include natural and artificial green areas, and the non-blue-green spaces refer to urban construction land excluding blue-green spaces. Evaluation of the classification results based on the Kappa coefficient showed an overall Kappa coefficient of 0.884, 0.864, and 0.883 for the data classification in the years 2004, 2011, and 2017, respectively, meeting research standards and accuracy requirements. The classification results effectively reflect the land use landscape pattern of the study area.

2.4 Landscape pattern analysis

Based on the feature level, the landscape pattern can be divided into three analytical levels: (1) patch level, representing the spatial characteristics of individual patches; (2) type level, reflecting the spatial characteristics of landscape patches of the same type; (3) landscape level, reflecting the spatial characteristics of the entire landscape mosaic. Landscape pattern indices are considered as the primary tools for quantitatively assessing landscape patterns, measuring the heterogeneity of different landscape elements in space or time, and characterizing their composition and distribution features [18]. Landscape pattern indices were calculated using Fragstats: three indices were selected at the patch level to study the correlation between the area, edge, and shape of the blue-green space patches and the internal temperature of the patches; one index was chosen at the type level to study the correlation between landscape components and unit land surface temperature, to analyze the thermal environment improvement effects based on the blue-green space landscape patterns level.

Considering that spatial patterns at different scales will gradually lose or alter landscape information characteristics[19], leading to differences in landscape analysis results for the same landscape, it is crucial to select an appropriate spatial scale. To mitigate the impact of landscape unit size on landscape patterns and thermal environment analysis differences, a Moving-Window Analysis is employed to investigate the relationship between thermal environment and blue-green spaces at multiple scales. By using GIS grid tools to partition surface temperatures within windows and resampling the average surface temperature within each window to characterize the thermal environment of the samples. Given that the remote sensing image pixel size used in this study is 30 meters × 30 meters, using smaller landscape units as the moving-window would result in a large computational burden and lead to overly homogenized landscape classifications, and the landscape classification below the window would tend to become more homogenized [20-22], reducing the significance of the research findings. Additionally, to ensure that each temperature pixel is independently contained within the moving-window and to minimize unnecessary calculations between overlapping pixels, it is preferable to choose a moving-window size that is a multiple of the pixel size. To summary, taking into account the unit scales used in landscape pattern analyses by Xu Shuang[23], Zou Jing [24], Shen Zhongjian[1,25], and others, the final selection includes five sizes for the moving-window: 300 meters × 300 meters, 600 meters × 600 meters, 900 meters × 900 meters, 1200 meters × 1200 meters, and 1500 meters × 1500 meters.

3 Results and analysis

3.1 Comparison of temporal and spatial evolution between thermal environment and blue-green spaces

At the overall urban pattern level, by comparing the data related to land surface temperature from 2004 to 2017 (Table 3) with the changes in the area of various land use patches (Figure 2), it was observed that there is a negative correlation between the area of green space patches and the average land surface temperature. During the period from 2004 to 2011, a significant amount of non-blue-green spaces were transformed into green spaces, which is associated with the implementation of Tianjin's Overall Urban Planning released in 2006. With the increase in artificially constructed green spaces, the green spaces system in the central urban area gradually improved, leading to a noticeable growth in the area of green space patches, especially in the southern parts of Hedong and Hexi districts. Simultaneously, the high-temperature range areas in these two districts decreased. Overall, the urban land surface average temperature in 2011 slightly decreased compared to that in

2004. However, from 2011 to 2017, the areas of blue-green space patches in the six districts of Tianjin decreased, resulting in a significant rise in the urban land surface average temperature.

Table 3 Data statistics of surface temperature

Date/year-month-day	Minimum temperature T_{min}/℃	Maximum temperature T_{max}/℃	Average temperature T_{mean}/℃	Standard deviation T_{std}
2004-07-06	26.77	51.93	39.43	3.90
2011-06-08	21.68	47.23	35.30	3.86
2017-07-10	29.12	52.91	41.13	3.93

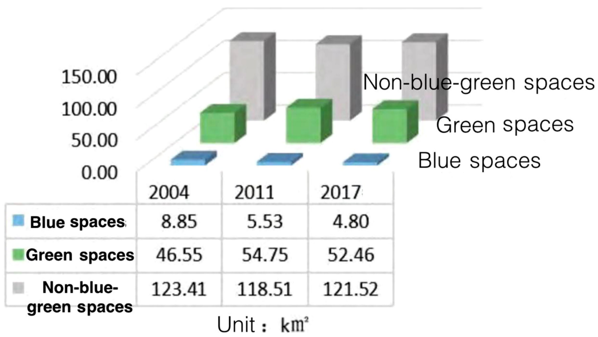

Figure 2 Comparison of land use patch areas by type from 2004 to 2017

Based on the interpretation of temperature difference zones and land use classifications, a comparative analysis of the temporal and spatial evolution of thermal environment and blue-green spaces in the six districts of Tianjin was conducted yearly. Additionally, a thermal environment profile analysis was carried out respectively in the north-south and east-west direction at the urban transport hub Tianjin West Station and Tianjin Station. This profile analysis traverses from the high-temperature range areas in the north to the low-temperature range areas in the south, passing through densely populated areas in the city core, which holds significant research value. In 2004 (Figure 3), the high-temperature range areas were primarily concentrated at the junction of Hebei and Hongqiao districts, followed by the northern parts of Nankai district, the banks of the Haihe River where Hebei, Hedong, and Hexi districts meet (Jinwan Square, Tianjin Station), and the eastern part of Hexi district. The low-temperature range areas were mainly concentrated around blue spaces such as rivers (Haihe River, North Canal, etc.), lakes (Tianta Lake, etc.), and large parks (Water Park, Beining Park, etc.) that include blue-green spaces, with the southwestern urban area forming the extremely low-temperature region. Additionally, low-temperature range areas were found in highly vegetated areas such as universities, like the Balitai area in Nankai district. From the analysis of the thermal environment profile, it was evident that different types of land use are significant contributors to the interleaving of peaks and valleys, with blue spaces serving as distinct low-temperature valley areas (Figures 4, Figures 5). In conclusion, it was found that the majority of urban low-temperature range areas are concentrated within blue-green spaces.

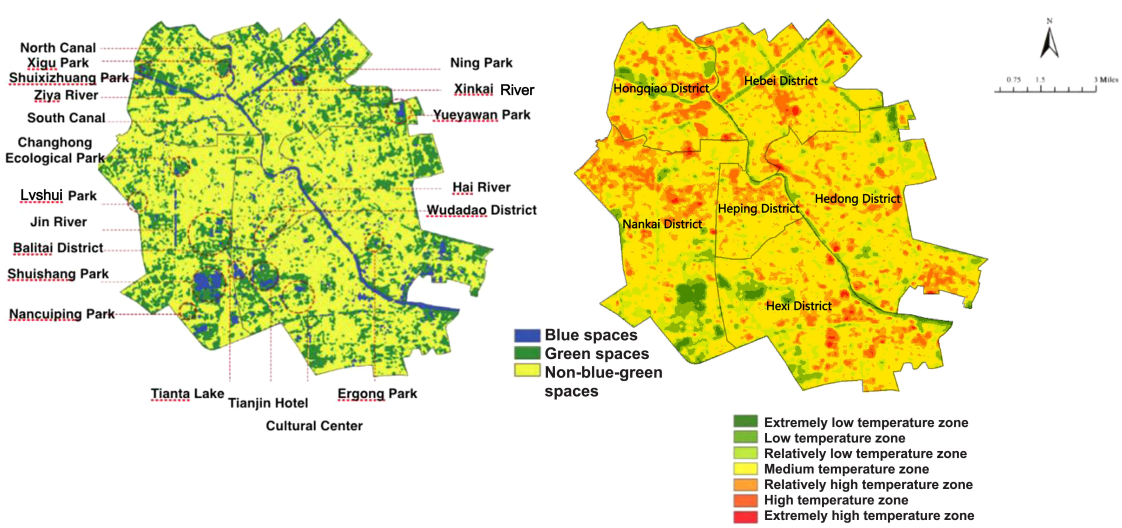

Figure 3 Contrasting analysis of blue-green spaces and thermal environment patterns in the six districts of Tianjin in 2004

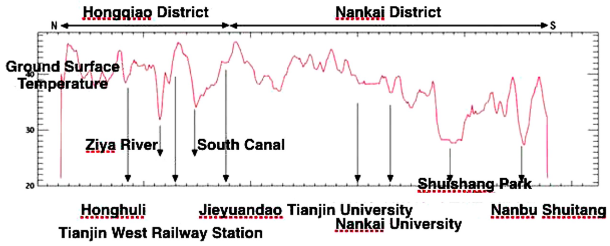

Figure 4 Variation of thermal environment in the north-south section in 2004

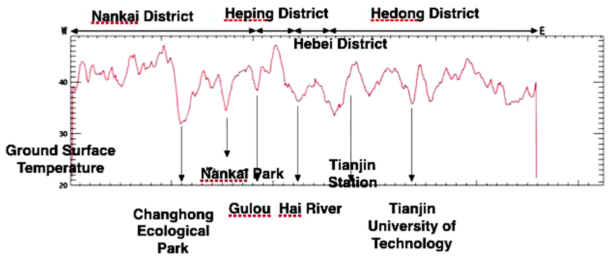

Figure 5 Variation of thermal environment in the east-west section in 2004

In 2011 (Figure 6), the high-temperature range areas began to expand outward, beyond the constraints of the river flows of Ziya River, South Canal, and Haihe River. Simultaneously, significant rise in ground surface temperatures can be observed across the entire Hedong District from the change diagram of the hot environment east-west section, with the emergence of multiple high-temperature peaks and a gradual increase in temperature differences at local levels. The low-temperature range areas still concentrate around blue-green spaces, but compared to the year 2004, there has been an overall reduction in the spatial layout, particularly noticeable in the southern part of Nankai District where the development of the Olympic Park has fragmented the area into disjointed hot environment patches. Additionally, a more intuitive change is the gradual decrease in north-south temperature difference depicted on the hot environment section analysis diagram, along with the addition of high-temperature peak areas in the south (Figures 7, Figures 8), further revealing the positive correlation between urban development land use and the hot environment, as well as the ameliorating impact of blue spaces on the hot environment.

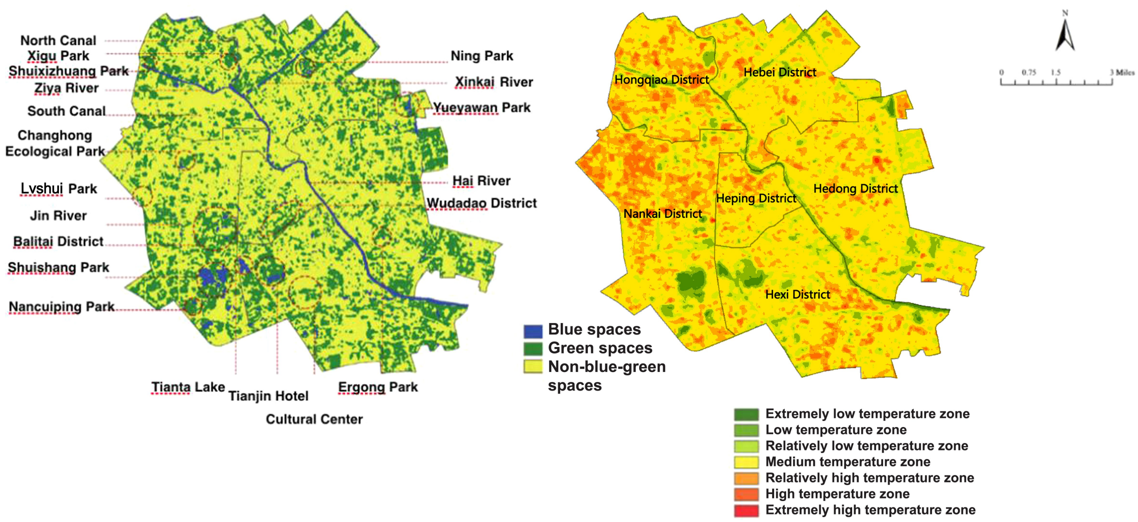

Figure 6 Contrasting analysis of blue-green spaces and thermal environment patterns in the six districts of Tianjin in 2011

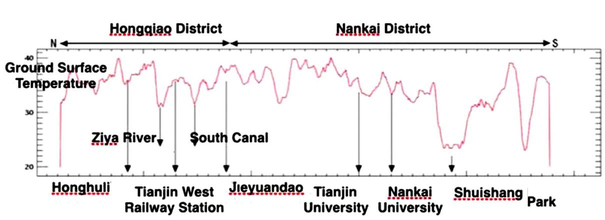

Figure 7 Variation of thermal environment in the north-south section in 2011

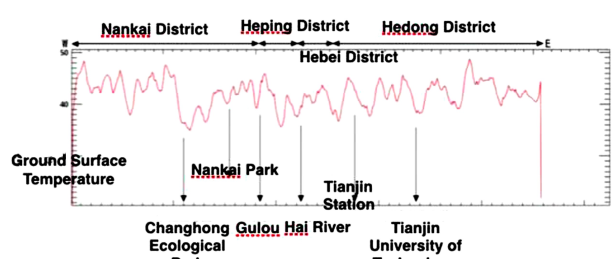

Figure 8 Variation of thermal environment in the east-west section in 2011

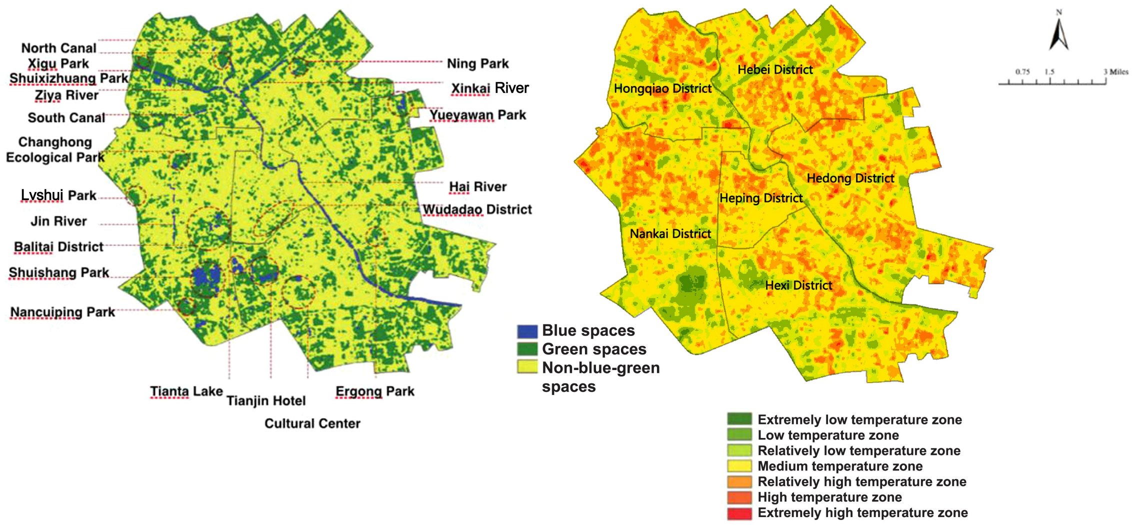

Figure 9 Contrasting analysis of blue-green spaces and thermal environment patterns in the six districts of Tianjin in 2017

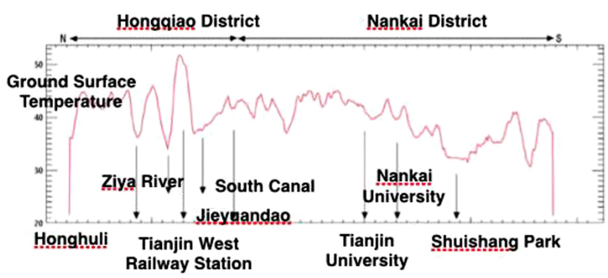

Figure 10 Variation of thermal environment in the north-south section in 2017

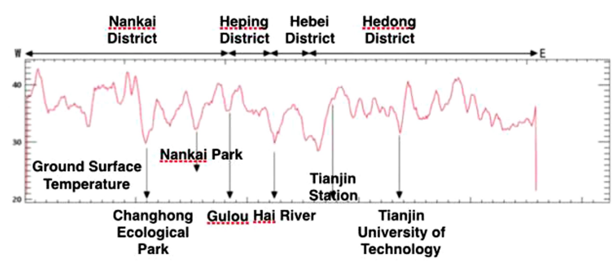

Figure 11 Variation of thermal environment in the east-west section in 2017

In 2017 (Figure 9), the high-temperature range areas expanded extensively from west to east across the Haihe River, notably displaying a more prominent clustering effect of hot environment patches in the Hedong and Hebei Districts compared to previous years. The ground surface temperatures in the north-south profiles show an overall rising trend, with the low-temperature valley in the southern part of Nankai District significantly higher than in 2004 and 2011 (Figures 10, Figures 11). Furthermore, the low-temperature range areas have seen the addition of numerous linear areas within the existing spatial layout, such as the northern rail line in the north of Hebei District and along the city moat in Hexi District, revealing the significant cooling effects of linear green spaces like strip protections and waterfront green spaces.

Examining the spatiotemporal evolution characteristics of the thermal environment and blue-green spaces in the six districts of Tianjin from 2004 to 2017, it is evident that the high-temperature range areas have been influenced by the urbanization process. With the continuous expansion of urban development directions, the early hot environment patches were relatively scattered, but later on, they expanded across river constraints and aggregated on a large scale. The development of urban construction land has a strengthening impact on the thermal environment. On the other hand, the low-temperature range areas continue to be prominently concentrated within blue-green spaces. This reveals the spatial connection between urban thermal environment and blue-green spaces, highlighting the significant improvement role of blue-green spaces in the thermal environment. Particularly, the cool islands formed by blue spaces play a crucial role in promoting heat exchange both within and outside the city.

3.2 Correlation between thermal environment and blue-green space landscape patterns

Taking the data from 2017 as an example, an in-depth analysis was conducted on the relationship between blue-green space patches and the thermal environment. In 2017, the average ground surface temperature of the six districts in Tianjin was 41.13℃, with the blue space patches at 38.7℃ (standard deviation of 2.63) and green space pat-

ches at 40.9℃ (standard deviation of 2.19), both below the overall average temperature. By analyzing the temperature distribution of blue-green space patches (Table 4), it was found that in the blue space patches, the proportion of low-temperature range patches exceeded half; while in the green space patches, the proportion of moderate-temperature range patches exceeded half, further revealing the more prominent cool island effect in blue spaces.

Table 4 Blue-green space patches temperature difference zoning statistics

	Blue spaces		Green spaces	
Temperature zone	Patches/piece	Percentage occupied by patches/ %	Patches/piece	Percentage occupied by patches/ %
Extremely low temperature zone	3	0.92	1	0.07
Low temperature zone	97	29.75	68	5.38
Relatively low temperature zone	98	30.06	197	15.58
Medium temperature zone	110	33.74	798	63.13
Relatively high temperature zone	15	4.60	180	14.24
High temperature zone	3	0.92	20	1.58
Extremely high temperature zone	0	0	0	0

The area, perimeter, perimeter-to-area ratio of blue-green space patches were selected, and their correlation with the internal minimum temperature was analyzed, with results shown in Table 5. The correlation analysis indicated a significant positive correlation between the internal minimum temperature of blue-green space patches and their perimeter-to-area ratio, a significant negative correlation with the perimeter, and a relatively lower correlation with the area. The correlation with the perimeter-to-area ratio was slightly higher than that with the perimeter. This suggests that the internal minimum temperature of blue-green space patches is more sensitive to changes in the perimeter-to-area ratio and perimeter, with a more complex shape and irregular edge of blue-green space patches providing stronger cooling effects compared to simpler and regular-edged patches. Optimizing the perimeter and perimeter-to-area ratio of blue-green space patches can significantly enhance their ability to improve the thermal environment.

Table 5 Correlation between temperatures of blue-green space patches and landscape pattern indices

	Landscape pattern index	Correlation coefficient with the minimum temperature within patches
Blue spaces	Patch perimeter	-0.461^{**}
	Patch area	-0.375^{**}
	Patch perimeter-to-area ratio	0.549^{**}
Green spaces	Patch perimeter	-0.415^{**}
	Patch area	-0.396^{**}
	Patch perimeter-to-area ratio	0.442^{**}

Note: ** indicates $P< 0.01$

3.3 Multi-scale connections between thermal environment and blue-green spaces

Using the moving-window method to divide the temperature difference zones obtained in 2017 into windows, the sample sizes were 1844, 421, 177, 90, and 54 respectively. The overlay of spatial patterns of thermal environment and blue-green spaces is depicted in Figure 12, indicating the relationship between thermal environment and blue-green space at different scales. The index of blue-green space patches area percentage in the samples was selected and correlated with the temperature from resampled samples, revealing a significant negative correlation between ground surface temperature and blue-green spaces at the landscape component level (Table 6). With increasing spatial scale, the correlation between the percentage of blue space patches area in the landscape and surface temperature gradually strengthens, reaching the highest in the 1500 meters × 1500 meters sample; while the correlation between the percentage of green spaces patch area in the landscape and surface temperature gradually weakens, peaking in the 300 meters × 300 meters sample. Regression analyses were conducted using the most strongly correlated blue-green spaces data, with both regression models passing significance level tests. The regression coefficient for the 1500 meters × 1500 meters sample and blue spaces were −0.211, and for the 300 meters × 300 meters sample and green spaces were −0.051. By comparing the regression coefficients, it is evident that blue spaces are

more efficient in improving the thermal environment compared to green spaces, and adjusting the proportion of blue spaces in the 1500 meters × 1500 meters scale is more effective in addressing thermal environment challenges.

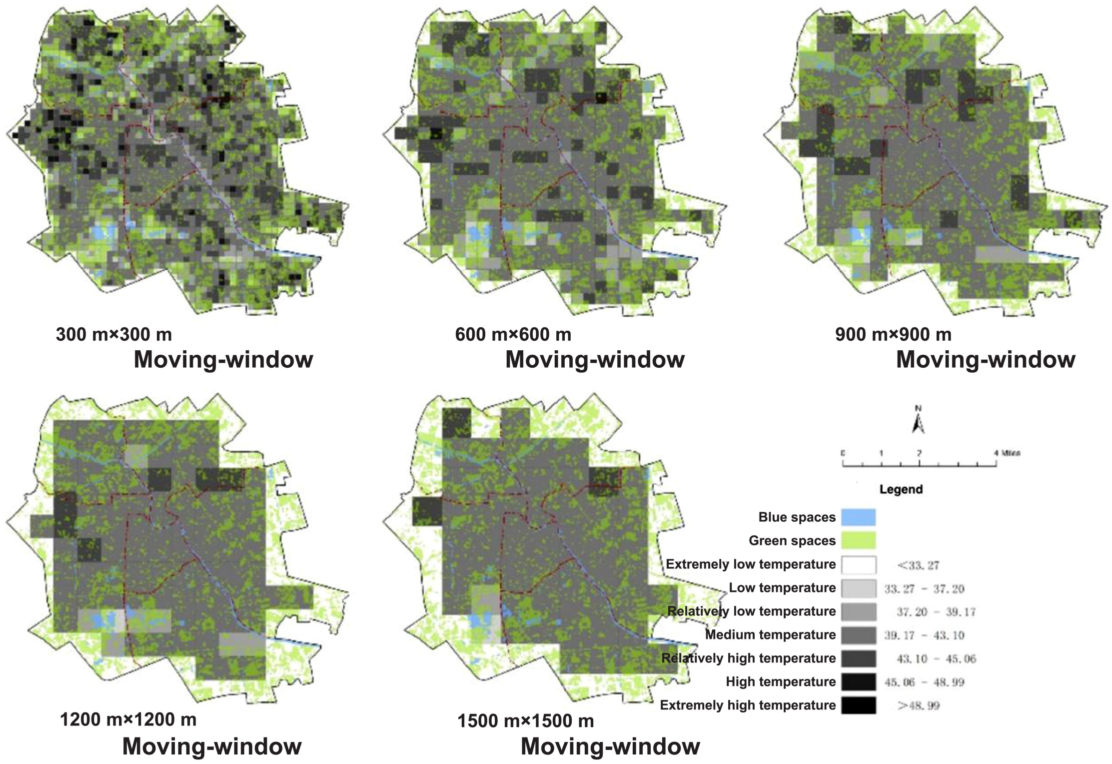

Figure 12 Comparison of the overlay of multi-scale sample thermal environment pattern and blue-green space patterns

Table 6 Correlation between sample temperature and landscape pattern index

Sample window scale	Correlation coefficient between sample temperature and percentage of landscape area occupied by patches	
	Blue spaces	Green spaces
300 meters × 300 meters	-0.604^{**}	-0.513^{**}
600 meters × 600 meters	-0.598^{**}	-0.492^{**}
900 meters × 900 meters	-0.630^{**}	-0.456^{**}
1200 meters × 1200 meters	-0.622^{**}	-0.452^{**}
1500 meters × 1500 meters	-0.724^{**}	-0.431^{**}

Note: ** indicates $P < 0.01$

4 Recommendations for improving thermal environment

Based on the relevant principles of enhancing urban thermal environment through blue-green spaces and considering the current status of thermal environment and blue-green spaces in the six districts of Tianjin, recommendations are proposed to optimize the blue-green space patterns and enhance the effectiveness of improving the thermal environment from the following three aspects.

4.1 Optimize the landscape pattern of blue-green spaces at the optimal scale

Research on the relationship between urban thermal environment and blue-green space landscape patterns reveals that increasing the percentage of blue spaces in the 1500 meters × 1500 meters spatial scale has the most significant cooling effect, while green spaces show significant effects at 300 meters × 300 meters scale. Blue spaces are more effective in improving the thermal environment compared to green spaces. Increasing the perimeter of blue-green space patches and reducing the perimeter-area ratio index can effectively enhance the thermal environment. It is recommended to optimize the landscape pattern indices targeting the optimal spatial scales of blue-green spaces and prioritize adjustments to the blue space landscape components to achieve optimal efficiency in improving the

thermal environment. Specific implementation strategies may include adding pocket parks, active water parks, street green spaces, etc., and optimizing the edge shapes of blue-green space patches at the urban design level.

4.2 Focus on increasing blue spaces within the high-temperature zones in the northern region

Through comparative studies on temporal and spatial evolution, it is observed that blue spaces have a more significant impact on improving the thermal environment compared to green spaces. Currently, the distribution of blue spaces within the six districts of Tianjin is uneven, with most water areas concentrated in the southern part of Nankai District, leading to a scarcity of water areas in other regions. It is recommended to focus on increasing blue space patches within the high-temperature zones in the northern region, especially in Hebei District and Hedong District. Strategies such as expanding the water surface area in Yueyawan Park and Er Gong Park in Hedong District, increasing water areas in Zhongshanmen Park, and adding blue spaces in the high-temperature zones at the border of Hedong District and Hebei District are suggested to alleviate the more prominent thermal environment issues in Hebei District and Hedong District.

4.3 Expanding the renovation of existing waterways and promoting greenways construction

The North Canal and Ziya River flowing through Hongqiao District, the Xinkai River in Hebei District, and the Hai River converging at the junction of the six districts collectively form the crucial river framework for improving the thermal environment in Tianjin, playing a significant role in cooling. However, the average width of the South Canal, Jin River, Weijin River, the city moat, and Yueya River is only about 25 meters, with some even narrower than 20 meters, much smaller than the Hai River, leading to a significantly reduced cooling effect. This paper proposes to locally widen and link the South Canal, Jin River, Weijin River, the city moat, and Yueya River while constructing riverside greenways on the basis of paying much importance to protect all of the rivers, aiming to enhance and maximize the cooling advantages of linear blue-green spaces.

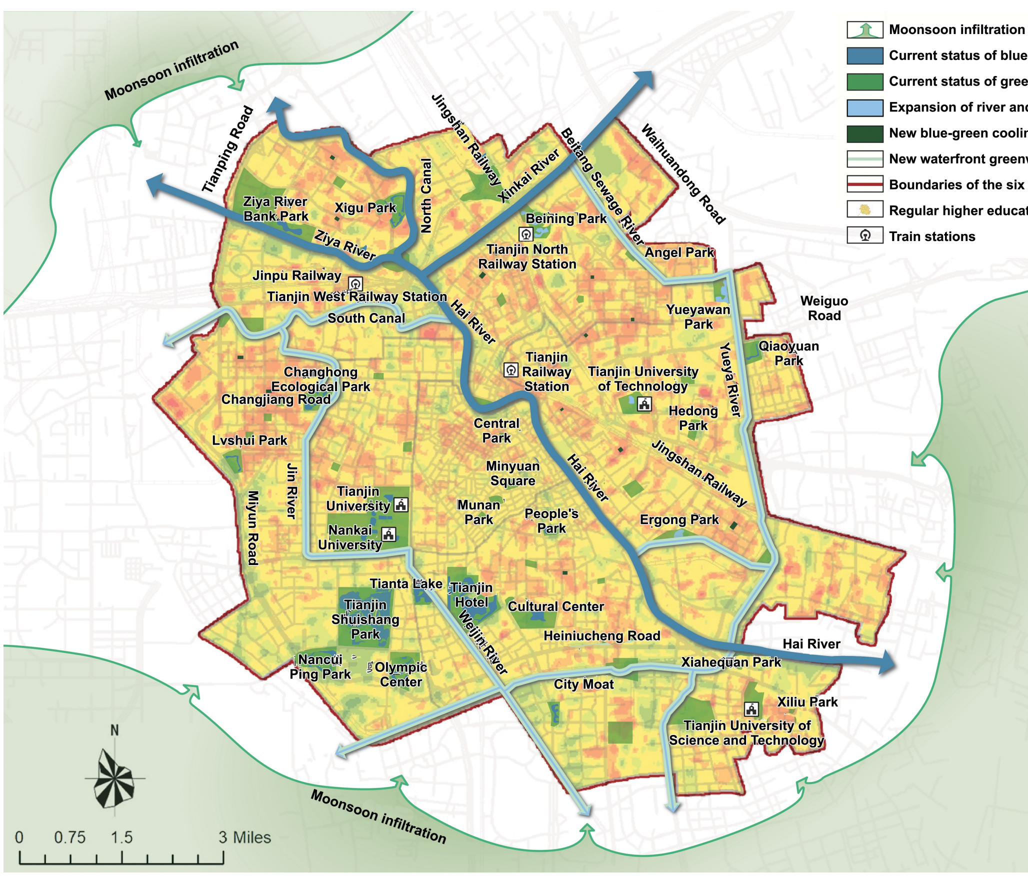

Figure 13 Suggested planning for blue-green spaces in the six districts of Tianjin city

By integrating the optimization measures mentioned above, the paper presents the blue-green spaces planning recommendations for the six districts of Tianjin as shown in Figure 13. Through optimizing the landscape pattern of blue-green spaces, increasing blue spaces within the high-temperature zones in the northern region, expanding and renovating waterways, and establishing riverside greenways, these strategies effectively address thermal environment issues, enhancing the city's ecology and livability.

Conclusion and outlook

Through the comparative analysis of the spatiotemporal evolution characteristics of the thermal environment and blue-green spaces in the six districts of Tianjin in 2004, 2011, and 2017, the following conclusions are drawn: (1) blue-green spaces play a significant role in improving the urban thermal environment. At the level of landscape pattern, ground surface temperature is significantly negatively correlated with the perimeter-area ratio of blue-green space patches and significantly positively correlated with the perimeter-area ratio index. (2) In the multiscale spatial pattern analysis, it is found that the ground surface temperature is most closely related to the ratio of blue space patches to landscape area in the 1500 meters × 1500 meters samples and most closely related to green space patches in the 300 meters × 300 meters samples, with blue spaces showing better thermal environment improvement efficiency. (3) Recommendations for thermal environment improvement based on optimized blue-green space landscape patterns are proposed.

Utilizing the cooling effect of blue-green spaces to improve the urban thermal environment has been a hot topic in recent years. This paper analyzed the relationship characteristics between the thermal environment and blue-green spaces at the level of landscape pattern, providing suggestions for addressing climate challenges and promoting ecological civilization construction. The conclusions drawn so far still have limitations in terms of spatial scale, and future research will continue to explore the patterns of the thermal environment and blue-green space landscapes at a finer scale to effectively harness the ecological cooling effects of blue-green spaces with precision and efficiency.

Figure and table sources

All figures and tables in this paper are drawn by the author.

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Content and Method of Studying Minority Traditional Villages and Dwellings Based on Cultural Geography

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ABSTRACT: It is of great significance to strengthen the research on minority traditional villages and dwellings for maintaining ethnic multicultural ecology and promoting the revitalization of rural culture. In ethnic minority villages and houses the urgency of the research and protection, this paper discusses the cultural geography for the applicability of the ethnic minority villages and residential research, from the cultural ecology, cultural diffusion, regionalization and integration, culture and landscape, space and place, the respect such as comprehensive mechanism illustrates the traditional residence in ethnic minority villages and cultural geography research content and the advantage. This paper probes into the methods of cultural geography to reveal the characteristic cultural connotation of minority traditional villages, which lays a foundation for deepening disciplinary research and protecting minority villages. Taking Yao nationality as an example, this paper puts forward the framework of minority villages and dwellings research, aiming to further promote the breadth and depth of minority villages and dwellings research.

KEY WORDS: *ethnic minorities*; *cultural geography*; *traditional villages and dwellings*; *Yao nationality*

1 Urgency and practical significance of research on traditional villages and residences of ethnic minorities

The history of the development of ethnic minorities in China is a continuous narrative of shrinking living spaces, as well as a narrative of ethnic integration, struggles, and reintegration. At a macro level, it is the irreconcilable ethnic contradictions that have historically given rise to nations [1]. However, in reality, many nations have integrated different ethnic groups. Therefore, when researching traditional villages and residences of ethnic minorities, it is essential to examine them through the lens of the laws governing human historical development. At a micro level, the production and daily life of various ethnic groups exhibit distinct regional, ethnic characteristics as well as fusion elements. To understand traditional villages and residences of ethnic minorities, one must delve into multiple factors such as their regional environment, migration processes, spatial differentiations, cultural exchanges, and historical evolutions to discern the patterns of their formation and evolution. Historical evidence suggests that national stability, social harmony, and economic development accelerate ethnic integration. Conversely, lack of stability can lead to differentiation and the splintering of ethnic groups, evolving into distinct national entities or beliefs. Throughout China's history, separations and mergers have resulted in as many as several hundred ethnic groups, but at the time of the founding of the People's Republic

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of China, less than 100 remained. Subsequently, 56 ethnic groups were officially recognized and established. Under the mindset of agrarian culture and self-sufficient economy, ethnic groups have often found it challenging to transcend temporal and spatial constraints and restrictive modes of production. Post-Song Dynasty, minority groups, together with the Han Chinese, faced an accelerated pace of assimilation and differentiation under the impact and influence of the market economy, leading to a gradual dispersal of ethnic groups. In modern times, as urbanization, industrialization, and modernization have progressed, the fusion among different ethnic groups has continued to strengthen. However, there are risks to ethnic cultures becoming homogenized and losing their distinctiveness. In reality, without the protection and support provided by the state to ethnic minorities, their numbers would likely decrease further, aligning with the laws of social development [2]. Nevertheless, this trend is detrimental to the preservation of cultural diversity and the advancement of civilization.

In the current prosperous and stable national environment, encouragement and support for the development of ethnic minorities are emphasized. It is essential to enhance the research on tangible and intangible cultures of ethnic minority villages and residences, exploring their traditional cultural spaces, cultural characteristics, revealing their processes and laws of survival evolution, and inheriting the diversification of cultural features of ethnic minority villages and residences. This is conducive to promoting the revitalization of rural areas in ethnic minority regions, fostering a strong sense of cultural confidence, and consolidating the diverse and integrated multiculturalism of the Chinese nation. Currently, research on traditional villages and historic cultural villages of ethnic minorities tends to focus on individual cases of typical villages and residences[3-4], as well as comparative studies of villages of different ethnicities in the same region[5]. These studies mainly describe the public spaces, morphological characteristics, housing construction techniques, cultural values, spatial structures, and development planning of villages and residences[6-9], emphasizing on capturing the static characteristics of rural and residential architecture itself and its environment, rare in the systematic and comprehensive investigation of one or several ethnic groups distributed across different provinces in terms of origin, migration, diffusion, cultural traits, and cultural delineation in the field of architecture studies. There is a lack of comprehensive research on the diffusion of cultural heritage, dynamic evolution, ethnic integration, and comprehensive mechanisms in ethnic minority villages. Furthermore, traditional villages and residential studies require broader spatial and temporal references to conduct comparative studies to its depth and breadth, otherwise it would be difficult to truly reveal their cultural significance and characteristics, thus constrain the development of the discipline. To address the aforementioned research gaps, it is necessary to move beyond traditional case study paradigms, gather enough sample materials, and establish a scientific foundation based on cultural geography. This approach helps identify spatial and cultural characteristics, cultural origins, differentiation, and evolution mechanisms, providing a more intuitive and manageable framework for classifying and exploring cultural dynamics and factors.

2 Applicability of cultural geography in researching traditional villages and residences of ethnic minorities

Drawing on theories from cultural geography and employing methods from the disciplines of architecture and planning, our team has conducted cultural geographical research on traditional villages and residences of the Hakka people in eight southern provinces of China. Through our studies focusing on village and residence types, historical evolution, cultural delineation, cultural landscape identification, and comprehensive mechanism research, we have achieved a series of significant advancements [10-16]. As our research scope broadens and our mechanisms deepen, we have gradually come to realize the importance and urgency of studying the culture of villages and residences of ethnic minorities, particularly the diffusion, integration, evolution process, and impact of Han Chinese and ethnic minority residential cultures within the context of ethnic integration which merit in-depth explora-

tion. Based on our research experience, by considering the distinctive characteristics of villages and residences of ethnic minorities, cultural geography demonstrates clear applicability in the study of traditional villages and residences of ethnic minorities: (1) the broadly-dispersed and small clustering nature of ethnic minority villages necessitates an analysis using broad coverage, diverse samples, and extensive data. Through comprehensive surveys, cultural geography treats ethnic minority settlements within a certain range as a holistic unit, enabling a comprehensive interpretation of the overall landscape of ethnic minority villages and the spatial differences and mutual influences among various residential cultures. This approach establishes the connection between ethnic residential culture and spatial and population subjects, facilitating a comprehensive and systematic understanding of the development patterns of traditional villages and residences of ethnic minorities.(2) The regional and ethnic characteristics of ethnic minority village and residential cultures are pronounced. When studying them, attention must be paid to the geographic environmental differences affecting the survival and migration of ethnic minorities, as well as to the inherent diversity within the ethnic groups themselves. The analytical framework of cultural geography that combines spatial and temporal elements is conducive to establishing links between various types of villages and residences, geographic environments, ethnic migrations, and cultural transmissions, integrating them into dynamic analysis and considerations of historical evolution. This approach establishes a multifaceted, multi-factor, cross-spatiotemporal analysis mechanism. (3) Cultural geography possesses distinct interdisciplinary characteristics. It can incorporate type differences emphasized by architecture, historical and cultural preservation concerns highlighted by planning disciplines, village organizational functions studied by sociology, and cultural changes examined by ethnology into a spatial and temporal analysis framework. By establishing a comprehensive analytical framework, cultural geography can reveal patterns and understand the essence at a greater scale, depth, and with more elements involved.

3 Content advantages of cultural geography in the study of traditional ethnic minority villages and residences

3.1 Research levels

As a sub-discipline of geography, cultural geography focuses on exploring the spatial characteristics of cultural phenomena, spatial patterns, and the relationship between culture and the environment. In the study of villages and residences, it can generally be divided into four levels of analysis: point, line, area, and volume (Figure 1). The "point" level focuses on studying the types and characteristics of typical villages and residences from the perspective of human-environment interactions, analyzing the factors such as natural, technological, and economic aspects that shape residential cultures. The "line (core)" level investigates the characteristics of the cultural origins of typical villages and residences and the pathways and patterns of migration, diffusion, and evolution from the place of origin. The study at the "area" level reflects spatial differences in the traits of residential cultures, the delineation of cultural areas, and the extraction of cultural landscape characteristics. The "volume" level establishes a comprehensive framework for analyzing the formation and evolution mechanisms of cultural areas and cultural landscapes from the aspects of natural, cultural, economic, technological, and political factors in the formation of village and residential cultures.

3.2 Research content and its advantages

(1) Conducting a comprehensive survey allows for a relatively complete entry of samples of villages and residences distributed in different regions, which is essential for revealing the patterns of formation and evolution of villages and residences on a larger scale. By conducting field surveys, collecting literature, using statistical yearbooks, satellite maps, remote sensing data, online databases, and other methods to obtain information on spatial location, site layout, topography, village morphology, public spaces, organizational functions, folk beliefs, residential forms, building materials, traditional techniques, decorative details of ethnic minority villages and residences, a basic analytical database can be established. These records

of cultural and historical information reflecting settlement environments, community patterns, residential forms, and components document ethnic minority group migrations, evolutionary trajectories, cultural dissemination, and historical heritage. Only through today's big data research can comprehensive geographical and multi-factor sample information entry be achieved, leading to a relatively rigorous analysis process and reliable research conclusions.

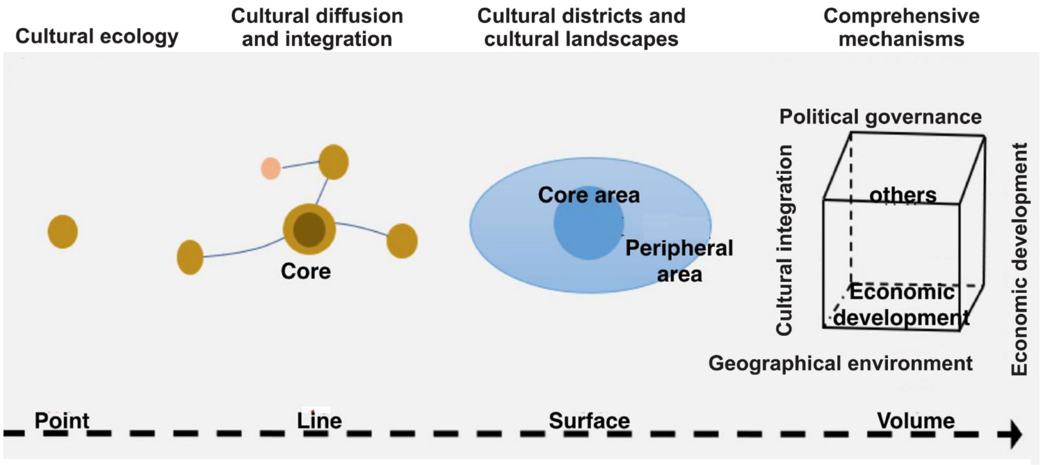

Figure 1 Levels of research on ethnic minority villages in cultural geography

(2) Cultural ecology establishes different cultural modes of habitation for different environments and ethnic groups by elucidating the process of human-environment interactions. Cultural ecology advocates studying the rules governing the emergence, development, and variation of culture from the interactions among various factors in the entire natural and social environment where humans exist, focusing on the study of the interaction between culture and the environment. By establishing systematic connections between ethnic residential culture and regional environment, cultural ecology reveals the territorial characteristics of ethnic groups and the ethnic characteristics of regions. For example, cultural ecological studies can effectively explain the differences and formation processes of villages and residential areas of the same ethnic group in different regions, as well as the landscape differences of villages and residences of different ethnic groups in the same region (Figure2). It shows how humans adapt to different environments and create cultural patterns with unique appearances under certain productivity conditions. For instance, how the Yao ethnic group in northern Guangdong utilizes mountainous environments to create a harmonious coexistence residential pattern under certain farming conditions, maintaining a good dynamic relationship between Yao villages and the environment (Figure 3).

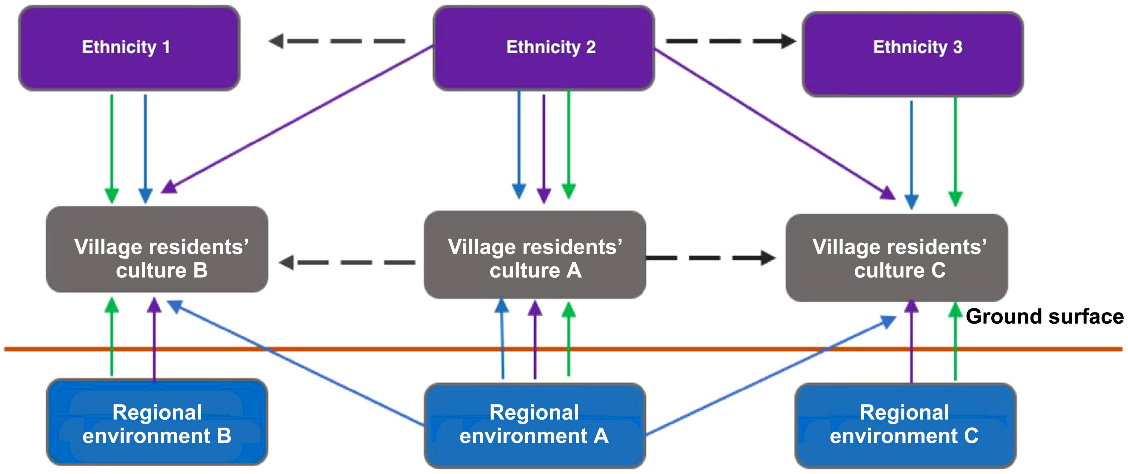

Figure 2 Relationship between regional environment, ethnicity, and village dwelling culture

Figure 3 Harmonious coexistence between Nangang Yao village in northern Guangdong and its surrounding environment

(3) Cultural geography mapping visually illustrates the traces of cultural diffusion and integration of ethnic minority villages and residences, enabling the exploration of the paths and modes of cultural diffusion of ethnic villages and residences. It delineates the paths and processes of ethnic cultural spatial evolution, revealing the laws of residential cultural diffusion and its impacts. For instance, in Yao villages (Figure 4, Figure 5), the Yao communities in southern Hunan, due to close interactions with the Han ethnic group and being situated on flat land, have been greatly influenced by the Han culture, resulting in courtyard-style residential houses. On the other hand, the Yao communities in northern Guangdong are more secluded and located in remote mountainous areas, leading to the development of a typical row house-style residential architecture. Conducting such studies horizontally benefits the preservation of the cultural characteristics of ethnic minority villages and residences in the context of ethnic integration, while vertically providing strategies for the inheritance of cultural heritage in ethnic minority villages and residences amid rapid urbanization and rural revitalization.

(4) Cultural geography's comprehensive study of traditional ethnic minority villages and residences contributes to the scientific delineation of cultural areas. The zoning of village and residential cultural areas is a spatial unit divided based on the differences in prevalent cultural traits in different regions, where the cultural elements of villages and residences in the same area, along with the landscape reflecting their cultural characteristics, exhibit consistent features. Due to regional variations in ethnic cultures, cultural geography enables a direct comparison of the types of villages and residences, cultural landscapes, internal patterns, and cultural traits of the same ethnic group in different regions or different ethnic groups in the same region. Through mapping and overlay analysis, distinct cultural areas can be delineated, and cultural core areas and peripheral areas can be scientifically identified based on typical cultural traits and concentration levels. Additionally, analyzing the dynamic evolution of cultural area structures helps in understanding the factors driving cultural evolution.

Figure 4 Residential courtyard of Yao People in Jianghua, Hunan

Figure 5 Linked row houses of Yao People in northern Guangdong

In the same geographical region, the differences in the landscapes of villages and residences of different ethnic groups can be explored to investigate the gradient relationship of ethnicity and cultural dissemination in ethnic fusion. For example, in the same region of Southeastern Guizhou Province, the Dong and Miao villages exhibit starkly different cultural characteristics (Figure 6, Figure 7). Dong villages are nestled among mountains and rivers, characterized by a marine influence with predominant public buildings, while Miao villages are often situated in high mountain valleys, lacking public structures and showcasing mountainous features.

Furthermore, cultural geography's historical perspective allows for the direct verification of village historical

changes through the analysis of village and residential landscapes across different time periods.

Figure 6　Village environment of Dong ethnic group in Qiandongnan, Guizhou

Figure 7　Village environment of Miao ethnic group in Qiandongnan, Guizhou

(5) Cultural geography through the study of the evolution of different residential cultural patterns, extracts internalized, fixed, and typical cultural landscapes and traits, which are beneficial for enhancing local cultural construction and inheriting excellent ethnic cultures in urban and rural development. Cultural traits serve as significant markers that distinguish one culture from another and are essential criteria for the delineation of village and residential cultural areas. By visually mapping out the major cultural landscape elements of villages and residences, cultural geography reveals the spatial aggregation and differences of a few typical cultural landscape elements. By identifying the differences between cultural landscapes in core areas and edge areas, comparing the roles of cultural landscapes in areas of ethnic fusion, deducing the historical evolution of typical regional cultural landscapes, cultural geography extracts representative cultural traits of ethnic villages and residences.

For example, Yao villages across generations have temples dedicated to the Pan King and often feature singing pavilions, while Dong villages typically include drum towers and covered bridges. When planning and designing in ethnic minority regions and creating regional identities, consideration should be given to the cultural traits of villages and residences in minority areas. This involves integrating the cultural characteristics of ethnic villages and residences into the development of material and spiritual civilization.

(6) The emerging cultural geography emphasizes the study of micro-cultural spaces in villages and residences, which can enhance the cultural and local identity of these communities. While big data surveys and statistical methods excel in identifying patterns within large samples, they often overlook individual differences since the real world does not conform to the ideal "rational actor" model. The frequent degradation of historical cultural heritage in urban and rural development fundamentally reflects a lack of recognition of the value of cultural heritage. Research on ethnic minority villages and residences needs to explore the rules of "space" from a macro perspective while also focusing on the formation of micro-level "local" culture. It is essential to transform the abstract, specific, and eternal "space" into concrete, heterogeneous, and changing "places", emphasizing the process through which "space" becomes "place".This approach highlights the connections between "space" and the environment, residents, specific affairs, establishes relationships between "space" and "people", and fosters a sense of local identity.

Figure 8　Utilization of newly-built drum tower in a Dong village

For instance, in Dong minority areas, when constructing new drum towers, some villages blindly pursue aesthetics, grandeur, and luxurious decorations (Figure 8). They may build elaborate drum towers at the entrances of

villages without considering the usage needs of the villagers and the function of the drum tower. This results in the loss of the significance and purpose of the drum tower, creating a cultural space that starkly differs from traditional drum tower spaces (Figure 9). Naturally, the villagers would not identify with such cultural spaces.

Figure 9 Utilization of an old drum tower in a Dong village

(7) The theories and methods of cultural geography provide a comprehensive analytical framework for examining the cultural characteristics, differentiation, evolution, and formation mechanisms of ethnic minority villages and residences, incorporating elements from nature, economy, culture, technology, and politics. The survival of ethnic minorities in a certain region typically spans centuries, and the establishment, settlement, development, and evolution leading to a "fixed" settlement pattern are the combined results of various factors. The natural environment is a significant influencing factor that manifests in specific housing patterns, for example, climatic conditions can affect the construction methods of houses, while topography can influence the choice of building materials and structures. However, Tomkins argues that climate and environment are just one of many factors that influence human production and life; the primary determinants are cultural beliefs, attitudes, and traditions.

When studying ethnic minority villages and residences, it is essential to establish a comprehensive analytical framework. Cultural ecology in cultural geography emphasizes the relationship between residential culture and nature, while cultural diffusion and integration focus on the impact of economic development and cultural blending. Cultural landscape analysis encompasses the driving force of technological progress and the regulation of ritual systems. The delineation of cultural regions embodies a synthesis of natural environment, ethnic culture, economic development, administrative boundaries, and technical standards. By analyzing traditional ethnic minority village and residence types, spatial distributions, and landscape variations from multiple perspectives of nature, economy, culture, technology, and politics, cultural geography facilitates the creation of a comprehensive analytical framework.

4 Research methods for cultural geography of traditional ethnic minority villages and residences

Taking Yao ethnic minority traditional villages and residences as an example, the Yao people are mainly distributed in several provinces such as Guangxi, Hunan, Guangdong, Guizhou, and Yunnan[17-18]. By accurately locating Yao villages on the map, it is evident that existing Yao villages are mainly found on both sides of the Nanling mountains and the Dayao mountain area. Yao villages are more concentrated on the southern side of Nanling than the northern side, and Yao villages with fewer populations in Guangdong, Guizhou, and Hunan are located near the border with Guangxi[19]. Observing the distribution of numerous existing Yao villages, it is clear that the vast majority of Yao villages are clustered in mountainous areas, with few settlements on plains or at the foot of mountains impacting flat lands. However, historical records and genealogical analyses indicate that a significant number of Yao ancestors settled on flatlands. The explanation for the predominance of Yao villages in mountainous areas today is often attributed to historical ethnic conflicts, oppression, and migration, while underestimating or even neglecting the role of cultural integration, cultural assimilation, and assimilation itself. Some Yao ancestors who inhabited flatlands had more frequent interactions and closer cultural integration with Han and other ethnic groups, gradually assimilating into the Han ethnicity.

Therefore, using the Yao people as a case study, integrating cultural geography theories with architectural methods, focusing on the cultural landscapes of Yao villages and residences (Figure 10), exploring the types of cultural characteristics using cultural ecology and cultural traits, investigating spatial variations in Yao residential culture through cultural diffusion and cultural zoning, ex-

amining the dynamic evolution of Yao residential culture through evolutionary forces and processes. This approach aims to address core issues such as the formation process, spatial differentiation characteristics, and evolution patterns of traditional ethnic minority villages and residences, in order to understand the characteristics and evolution mechanisms of traditional ethnic minority villages and residences. It seeks to reveal the evolving trends of Yao traditional villages and residences under the backdrop of cultural integration, providing insights for the inheritance of Yao traditional village characteristics and cultural revitalization.

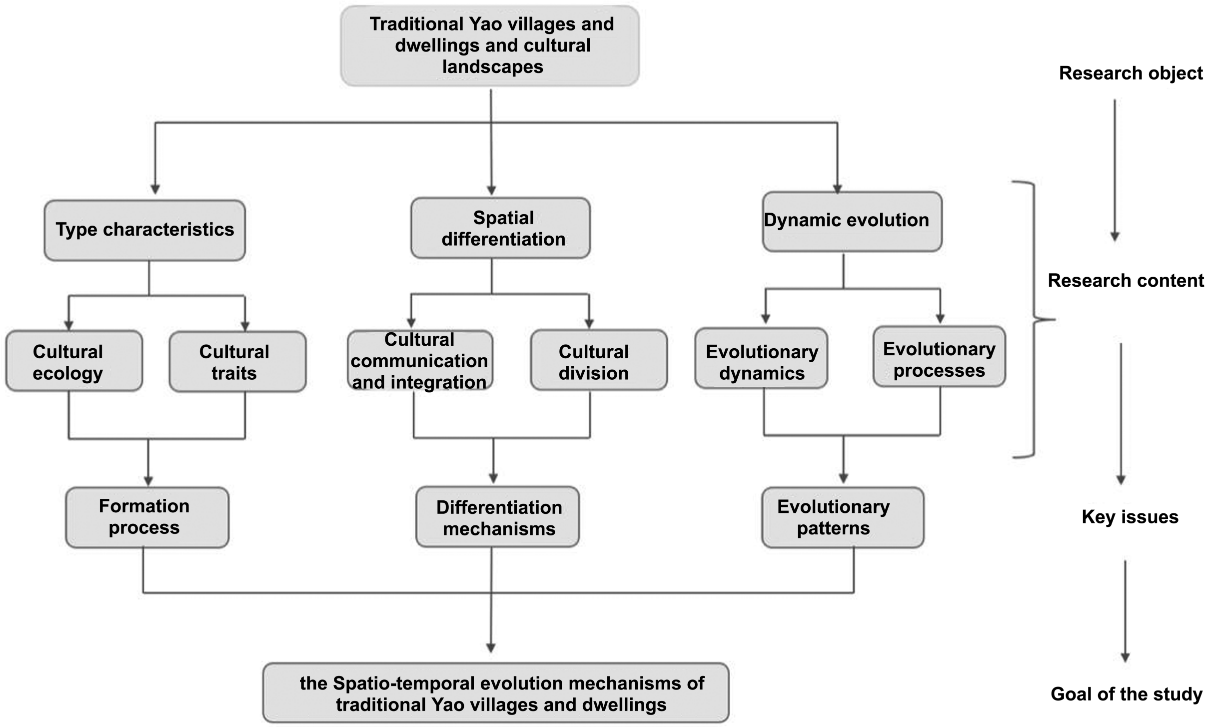

Figure 10 Research framework of traditional Yao ethnic village and residential cultural geography

Conclusion

Traditional settlements and residences are one of the largest historical and cultural carriers of human society, reflecting the relationship between people and land with distinct regional and cultural characteristics. Ethnic minority villages and residences possess their own uniqueness, being inherent in the agrarian civilization. In the process of modern social development, the evolution of these ethnic minority villages has been increasingly influenced by external factors. Research on traditional ethnic minority villages and residences should not only consider their specific geographical locations in relation to human and environmental interactions but also incorporate them into comparative studies of cross-cultural exchanges. It should analyze the formation of residential culture in a historical context and focus on the historical evolution during social changes. Cultural geography, using ethnic minority villages and residences as cultural landscapes, examines the relationship between residential culture and the natural geographical environment from a cultural ecology perspective. It explains the pathways and spatial processes of residential culture dissemination from the perspective of cultural diffusion, identifies ethnic cultural characteristics from the standpoint of cultural traits, examines the evolution of residential culture from the perspective of cultural landscape changes, and comprehensively interprets the mechanisms of the formation and evolution of residential culture from the angle of cultural zoning. By comprehensively applying cultural geography, the understanding of ethnic residential cultural patterns can be deepened, existing research outcomes can be integrated, and research on ethnic minority villages and residences can be advanced on a larger scale and deeper level.

Figure and table sources

Figures 1-10 in this paper are all self-drawn or self-cap-

tured by the author..

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Research on the Evaluation of Street Space Friendliness of Residential Blocks :Based on Residents' Subjective Observation Perspective

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ABSTRACT: This paper takes 20 residential streets in Hexi district of Nanjing as the research objects, investigates pedestrians' subjective perception and object environment data of the street space environment, analyzes pedestrians' psychological evaluation structure of the street which includes social interaction, spatial atmosphere, vegetation and facilities. On the basis of each evaluation score of the streets based on the common factors,the paper studies the correlation between the subjective evaluation of the street and the object index, concludes the influence mechanism of street object indicators on residents' psychological perception, and explores the street space environment indicators that are conducive to pedestrian-friendly residential blocks.

KEY WORDS: *walking-friendly*; *residential blocks*; *street space*; *Semantic Differential*; *correlation*; *subjective observation*

1 Background

Residential neighborhood streets refer to urban roads that divide residential blocks (neighborhoods) within a residential area. As the most frequently used spatial carrier for residents' daily commuting, leisure activities, and various life activities, these streets serve not only the transportation functions but also create community interaction spaces with social attributes. However, many streets exhibit pedestrian-accessible issues such as excessive width, uneven distribution of road rights, monotonous spatial experiences, and poor road maintenance. In the current urban environment development shifting from "incremental" to "quality improvement", there is a necessity for detailed and scientific research on street spaces to address these shortcomings. Exploring the relationship between residential neighborhood street space environment and walking behavior from residents' subjective perspectives is of great theoretical and practical significance for establishing a pedestrian environment evaluation system and fostering pedestrian-friendly cities.

Many studies on the quality of street walking environments mainly focus on exploring the impact of pedestrian-friendly environmental elements and built environment elements on residents' walking behavior at a macro level. Scholars such as Cervero R (1997), Southworth M (2005), Koohsari M J (2016), Chen Yong (2017), and Lu Peidong (2019) have proposed relevant environmental indicators of walkability, including land use mix, road net-

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work connectivity, accessibility of facilities, and commercial density. Other scholars have examined the influence of street spatial form, scale, streetscape characteristics, and municipal facilities on walking behavior at a micro level. Scholars like Jaskiewicz F (2000), Purciel M (2009), and Dover V (2013) argue that factors such as street enclosure, pleasant scale, tree canopy coverage, and sidewalk facilities contribute to enhancing residents' willingness to walk [6-8]. Studies by Shin W H (2011), Liu Jun (2017), Yin L (2016), focused on the specific preferences of walking behavior for particular groups, highlighting the impact of micro-environmental variables in the street such as greenery density, effective pedestrian pathway width, and green view rates [9-11]. Compared to foreign research, which has achieved multi-disciplinary comprehensive studies in this field, related research in China is still in its early stages. Considering the importance of residential neighborhood street spaces for the lifestyle and travel mode choices of residents within the community circle, especially for the widespread enclosed residential neighborhoods in China, there is a need for a comprehensive study from the urban design perspective based on subjective measures. Research on the constituent elements of street spaces and their relationship with walking behavior in residential neighborhood streets, from the perspective of urban design, incorporating emotional perception measures and psychological evaluations of pedestrians, is essential.

This study focuses on 20 residential neighborhood streets in the Hexi area of Nanjing city. It conducts a questionnaire survey using the semantic differential method to assess pedestrians' psychological perceptions and emotions. Additionally, data on the built environment of the streets are collected through drawings and on-site measurements. Based on this data, factor analysis is employed to extract common factors in the evaluation of street design (SD), determining the psychological evaluation structure of pedestrians towards the streets and the evaluation scores of each street based on these common factors. This approach aims to stratify and quantify residents' subjective perceptions of the streets. Subsequently, a mathematical model is established to analyze the correlation between various indicators at different levels, such as spatial scale, boundary spaces, functional facilities, street greening, within the built environment of the streets and residents' subjective ratings. This analysis aims to identify street environmental elements that significantly influence subjective perceptions, thereby providing recommendations for enhancing the pedestrian-friendliness of the streets. The research outcomes aim to provide reference and guidance for spatial construction and design guidelines for residential neighborhood streets, particularly those in high-density, enclosed residential areas. The streets studied in this research are open urban streets adjacent to residential land within residential neighborhoods, often serving as boundaries between different residential blocks.

2 Research methods

2.1 Semantic Differential method

The Semantic Differential method quantifies subjects' psychological perceptions through verbal scales to obtain their feelings towards the research subject and establish quantitative data. Currently, it is widely used in fields such as psychology, sociology, market research, and landscape design. The evaluation factors in the Semantic Differential method consist of sets of adjective pairs, each pair comprising two words with opposite meanings to express positive and negative connotations. Each set of adjective pairs generally includes 5 or 7 rating intervals and values to represent the intensity of psychological feelings, translating affective assessments into quantitative evaluations.

Compared to commonly used methods and tools in Europe and America such as PERS, NEWS, and CSR, the SD method utilizes adjective pairs that represent pedestrians' psychological perceptions, placing relatively more emphasis on pedestrians' emotional aspects.

2.2 Sample selection for survey

The samples are located in the Longjiang and Olympic Sports Center (OTC) areas of Nanjing, both situated on the west side of the old city. These areas were constructed from the late 1990s to the mid-2000s and from the mid-2000s to the mid-2010s, intended to alleviate population pressure in the old city by developing new urban areas characterized by high residential land use ratios, well-e-

quipped functional facilities, and mature development (Figure 1). Residential neighborhoods in these areas predominantly feature enclosed block forms with plot ratios ranging from 1.8 to 2.5. The road network density in these areas is lower than that of the old city, ranging from 8 to 9.5 km/km2. Longjiang was developed earlier than the Olympic Sports Center, featuring relatively smaller block and street spatial scales with more organic street forms and relatively outdated street facilities. In contrast, the Olympic Sports Center boasts larger spatial scales, a well-organized grid road network, and relatively improved street facilities.

This study selected 20 residential street sections with typical spatial characteristics based on the functional attributes of the streets, land use types on both sides, road grades, spatial scales, and enclosure interface types (Figures 2-3). These 20 streets are situated between residential neighborhoods (districts) and are classified as urban secondary roads and service roads. The land uses on both sides of the streets are residential, with one side of L8 surrounded by educational land walls. Residential buildings along the Longjiang streets primarily consist of 6-11 floors, while the Olympic Sports Center features predominantly high-rise residential buildings ranging from 18 to 31 floors. Enclosure interfaces include a single type or a combination of commercial spaces along residential complexes, community fences, squares, and green spaces. Pedestrian spaces are included in all road allocations. The study sections of the streets are delimited by the endpoints of two blocks at intersections and road redlines, with street lengths ranging from 180 to 380 meters.

2.3 Research content and data collection

The research content consists of two parts: street psychological perception and built environment. The survey on street psychological perception uses the Semantic Differential (SD) method, conducting surveys through questionnaires to investigate pedestrians' emotional responses and perceptual evaluations of the sampled streets. The research on the built environment utilizes CAD terrain maps as the foundational data, combined with on-site investigations for data correction to obtain spatial element data. The content includes sub-indicators on four aspects: overall street spatial scale, boundary spaces, functional facility layout, and street greening.

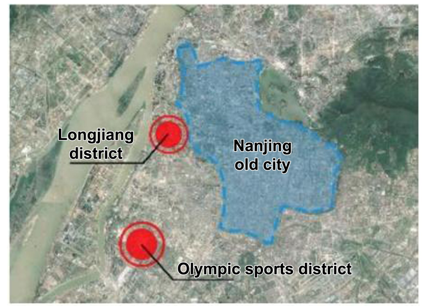

Figure 1 Schematic of the location of AoTic and Longjiang districts

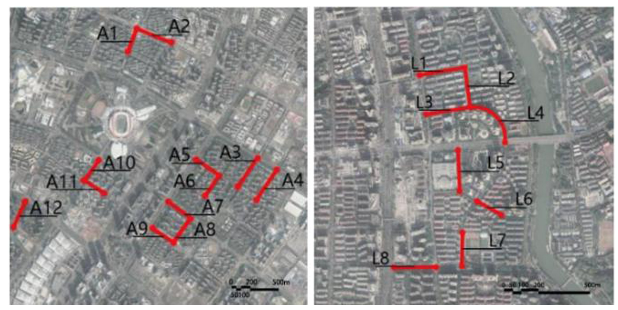

Figure 2 Schematic of the positions of the 12 streets in AoTic district and the 8 streets in Longjiang district

(1) Street psychological perception

Based on the characteristics of residential streets, this paper considers the impact of street spatial environment, ambience creation, and attractiveness on pedestrian behaviors and psychology. Drawing on the research experiences of several scholars [16-18], 15 sets of adjectives were selected as subjective evaluation factors, including: satisfaction, comfort, tranquility, liveliness, activity richness, interest, attractiveness, spatial openness, convenience, landscape richness, street tidiness, safety, tree shade density, facility completeness, and daily communication richness. Each evaluation factor is rated on a 5-point scale: very poor, poor, fair, good, very good, corresponding to scores of-2,-1, 0, 1, 2 respectively.

The survey was conducted by 20 graduate students majoring in architecture using interview-style questionnaires over 2 days. Each street planned to distribute 25 questionnaires, totaling 500, with 487 effective questionnaires ultimately collected, achieving a 97% response rate. Respondents were screened through inquiries to ensure they were local residents before proceeding with the ques-

tionnaire interview to ensure that the respondents were long-term users of the street and familiar with the living environment. Emphasis was placed on balanced age and gender distribution in participant selection. The survey was conducted on weekends to ensure diversity among respondents. In the surveyed areas, the male-to-female ratio of respondents was 1.25; the age distribution included 8.2% in the 12-18 age group, 39.8% in the 18-30 age group, 40.4% in the 31-60 age group, and 11.4% aged 60 and above; educational levels comprised 28.3% with education below college level, 50.9% with college education, and 20.7% with master's degree or higher. The demographic structure of respondents in the two areas was similar, with proportions close to the overall statistical average.

Figure 3 Photorealistic image of sample street

(2) Street built environment

The street built environment includes data collection on four spatial attribute levels. The overall spatial scale involves three indicators: street length, street width, and street height-to-width ratio to reflect the basic spatial scale of streets. Boundary space spatial elements refer to linear spaces between streets and adjacent residential areas that impact pedestrian behaviors, including sidewalk width, boundary permeability coefficient, density of community entrances and exits, density of node public squares, and proportion of commercial interaction interfaces. Street functional facilities are divided into public service facilities and public engineering facilities, providing various building facilities for public services and service facilities for transportation and activities, with related indicators such as the quantity of along-street functional facilities, functional mix, density of along-street seating, density of bicycle parking areas, density of bus stops, and density of crosswalks. Street greening includes indicators such as boundary greenery density, isolation greenery density, tree shade ratio, coverage ratio of shrubs and trees, and green view ratio (Table 1).

3 Data statistics and preliminary analysis

3.1 Psychological measurements

Statistical analysis was conducted on the questionnaire survey data to obtain the SD measurements of pedestrians' perception of street space in each street (Table 2). The average scores of factors in both areas mostly ranged between 0-1, indicating a tendency towards positive evaluations. The Olympic Sports Center area tended towards a "good" standard, while the Longjiang area tended towards a "fair" standard; both areas had negative evaluations in the "convenience" factor.

By comparing the scores of various factors between the two areas, it was observed that pedestrians in the Olympic Sports Center area had slightly higher overall satisfaction with the streets compared to the Longjiang area. Additionally, the factor evaluation scores for comfort, tranquility, attractiveness, openness, landscape richness, street tidiness, safety, and richness of daily communication spaces were all higher in the Olympic Sports Center area than in the Longjiang area. This to some extent reflects the recognition of the Olympic Sports Center area in terms of pedestrian space scale and street landscape construction. On the other hand, the Longjiang area scored slightly higher in factors such as richness of street activities, interest, and completeness of facilities, indicating a certain advantage in resident activity participation and completeness of living facilities.

Table 1 Conceptual definition and quantification of built environment indicators

	Indicators	Conceptual definition	Quantitative formulas
Overall spatial scale	Street segment length	Total length of street segments in sample streets	—
	Street width	Average crossing width for pedestrians	Streetaveragewidth $W_r = S_r/n$ S_r is the total length of crossing facilities, n is the number of crossing facilities
	Street height-to-width ratio	Weighted ratio of building height to street width along the street	Streetaspectratio $P_i = \sum_{i=1}^{N} h_i \times l_i/d_i \times L$ h_i is the height of building i along the street, l_i is the length of building i along the street, d_i is the distance from the building along the street to the road centerline, L is the length of the street segment
Boundary space	Sidewalk width	Effective average width of sidewalks	SidewalkWidth $W_s = S_e/L$ S_e is the effective area of the sidewalk, L is the length of the street segment
	Interface transparency coefficient	Degree of enclosure and openness of street boundary enclosure interfaces; dividing interfaces into three categories: closed, semi-closed, and open, with relative values assigned to reflect their transparency based on different material forms	Transparency Coefficient $C = 0^* a_1 + 0.5^* a_2 + 1^* a_3/L$ a_1、a_2、a_3 are the lengths of closed, semi-closed, and open interfaces respectively; L is the length of the street segment
	Entrance and exit density of the neighborhood	Average number of entrances and exits to residential neighborhoods per unit length of street	Entranceandexitdensityoftheneighborhood $D_c = N_c/L$ N_c is the total number of entrances and exits to neighborhoods along the street, L is the length of the street segment
	Node density of public plaza	Total area of public plazas along the street per unit length of street	Nodedensityofpublicplaza $D_g = S_g/L$ S_g is the total area of public plazas along the street nodes, L is the length of the street segment
	Ratio of commercial interactive interfaces	Percentage of building interfaces with main functions of shopping, dining, and lifestyle services	Ratioofcommercialinteractiveinterfaces $F_b = L_b/L$ L_b is the total length of commercial interactive interfaces on the street, L is the length of the street segment

Table 1 (continued)

		Indicators	Conceptual definition	Quantitative formulas
Functional facilities	Public service facilities	Number of functional facilities along the street	Number of Points of Interest (POIs) for service facilities on both sides of the street	—
		Degree of functional mix	Balance of types and quantities of functional facilities along street buildings; measured by the average information entropy	Degreeoffunctionalmixalongstreetbuildings $H_s = -\sum_{i=1}^{N} P_i \times \log P_i$ $P_i = \frac{A_i}{\sum_{i=1}^{N} A_i}$ P_i is the probability of information entropy of facilities of class i, A_i is the quantity of class i facilities
	Public engineering facilities	Density of street seating	Length of street seating per unit length of street	Densityofstreetseating $D_s = L_s/L$ L_s is the total length of public seating along the street, L is the length of the street segment
		Bicycle parking area density	Area of bicycle parking zones along the street per unit length of street	Bicycleparkingareadensity $D_z = S_z/L$ S_z is the area of bicycle parking zones along the street, L is the length of the street segment
		Bus stop density	Number of bus stops per unit length of street	Busstopdensity $D_b = N_b/L$ N_b is the number of bus stops along the street, L is the length of the street segment
		Crosswalk density	Number of crosswalks per unit length of street	Crosswalkdensity $D_m = N_m/L$ N_m is the number of crosswalks, L is the length of the street segment
Street greenery		Boundary greening density	Area of boundary greening per unit length of street	Boundarygreeningdensity $D_b = S_b/L$ S_b is the total area of boundary greening, L is the length of the street segment
		Isolation greening density	Area of isolation green belts per unit length of street	Isolationgreeningdensity $D_i = S_i/L$ S_b is the total area of isolation green belts, L is the length of the street segment
		Shade rate of trees	Proportion of shading area from the vertical projection of street trees' canopies on the road surface	S_y is the shading area from the vertical projection of the canopies of street trees, S is the area of the street
		Coverage ratio of Shrubs and trees	Ratio of shrub greening area to tree shading area	Coverageratioofshrubsandtrees $R = S_s/S_y$ S_s is the area of shrub greening, S_y is the area of tree shading
		Green view rate	Average proportion of green elements in 6 points and 18 pedestrian view images extracted using the Segnet technology for image semantic segmentation based on street view image data	Greenviewrate $V = \sum_{i=1}^{N} g_i/p_i$ g_i is the green elements in pedestrian view images, p_i is all elements in pedestrian view images

Comparing the SD evaluation curves visually (Figure 4, Figure 5), it can be observed that the fluctuation range of the evaluation curve in the Olympic Sports Center area is smaller than that of Longjiang, reflecting a more balanced evaluation of street construction in various aspects and higher overall acceptance. In contrast, the differences in evaluations in Longjiang are more pronounced, with clear strengths and weaknesses. Furthermore, the evaluation curves in the Olympic Sports Center area tend to be more similar to each other compared to Longjiang, indicating a closer alignment between the spatial characteristics and acceptance levels of each street in the Olympic Sports Center area, while there is greater variability in the spatial characteristics and evaluation differences among different streets in Longjiang.

Table 2 Statistical analysis of average scores of subjective perception by sample streets using the semantic differential method (SD)

District	Satisfaction	Comfort	Quietness	Vibrancy	Activity abundance	Amusement	Attractiveness	Openness	Convenience	Landscape abundance	Street frontage neatness	Safety	Canopy coverage	Facilities completeness	Social spaces diversity
Olympic sports	0.99	1.04	0.72	0.32	0.06	0.07	0.28	0.76	- 0.05	0.54	0.98	1.01	0.87	- 0.11	0.33
Longjiang	0.62	0.51	0.24	0.48	0.14	0.12	0.18	0.22	- 0.11	0.13	0.40	0.59	0.74	0.09	0.03

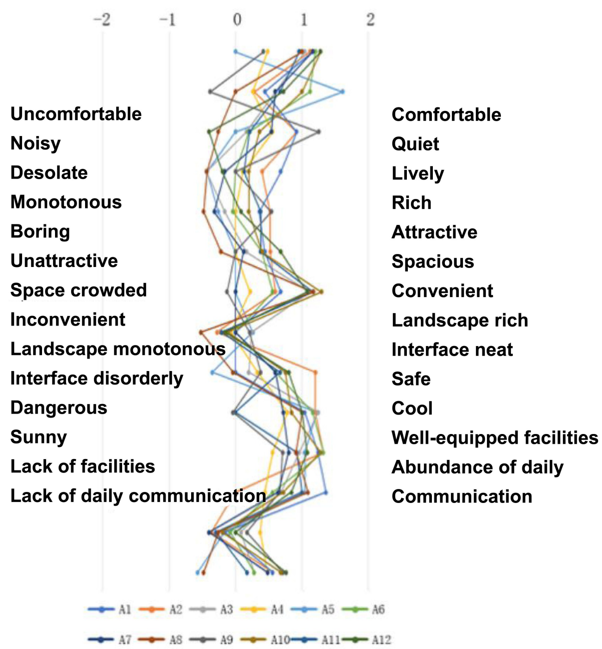

Figure 4 Evaluation curve of street design in sample streets of the Olympic sports center area (SD)

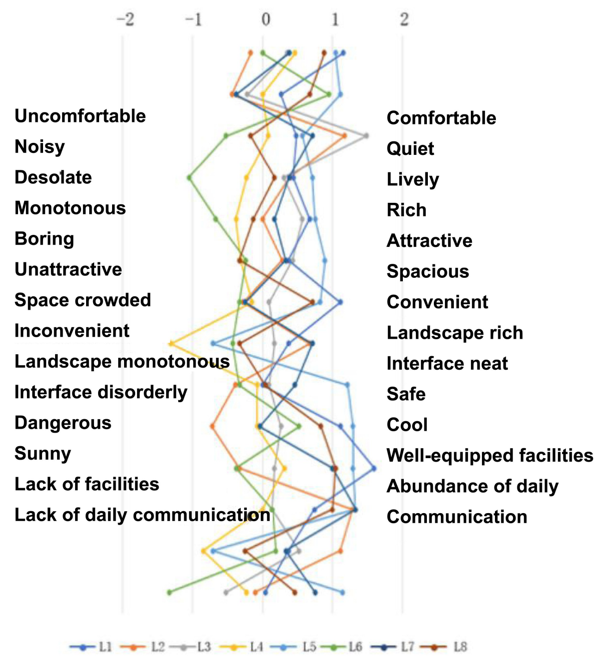

Figure 5 Evaluation curve of street design in sample streets of the Longjiang area (SD)

3.2 Completed environmental data

The statistics of related indicators in four aspects of the overall spatial scale, boundary space, functional facilities, and street greenery of the built environment are as follows (Table 3).

Overall spatial scale: the average street length in both areas is approximately 300m and 220m, with average street widths around 40m and 24m. In the Olympic Sports Center (OSC), both street length and width are higher than Longjiang. The comparison of average height-to-width ratio of streets shows that the ratio is 0.9 in the OSC, lower than the 1.4 in Longjiang.

Table 3 Street built environment data statistics table

District	Overall spatial scale			Boundary space					Functional facilities						Street greenery				
	Length of street segment (m)	Street width (m)	Street height-to-width ratio	Sidewalk width (m)	Transparency coefficient of interface	Residential entrance density (units/100m)	Node public square density (m2/100m)	Percentage of commercial interactive interface	Mixing degree of functions	Number of street service facilities	Density of street seats (units/100m)	Density of bicycle parking areas (m2/100m)	Density of bus stops (units/100m)	Density of crosswalks (units/100m)	Boundary greenery density (m2/100m)	Isolation greenery density (m2/100m)	Canopy coverage of deciduous trees	Coverage ratio of evergreen trees	Green view ratio
Olympic sports	296.17	39.25	0.91	2.41	0.51	0.4	196.2	0.23	0.485	14.75	4.1	21.5	0.4	0.7	280.2	153.4	0.28	0.22	0.54
Longjiang	219.50	23.50	1.43	1.73	0.56	0.9	40.1	0.26	0.532	14.25	3.6	38.9	0.1	0.6	285.8	96.3	0.67	0.11	0.49

Boundary space: the average values of the interface permeability coefficient and the proportion of commercial interactive interfaces are similar in both areas. The effective width of sidewalks in the OSC is 2.4m, higher than the 1.7m in Longjiang; the density of entrance and exit points in residential areas shows that there is an entrance or exit nearly every 200m, lower than the 0.9 per 100m in Longjiang. The density of public squares in the OSC is significantly higher than in the Longjiang area, providing relatively more densely distributed outdoor activity spaces.

Functional facilities: the functional mix of Longjiang along the streets is slightly higher than in the OSC, with a relatively greater variety and more balanced distribution of different types of functional facilities. In terms of public engineering facility-related indicators, the difference in seat density and crosswalk density between the two areas is not significant. The density of bus stops along streets in the OSC is higher than in Longjiang, while the density of bicycle parking areas along streets is lower than in Longjiang.

Street greenery: the average values of boundary greening density indicators are basically the same in both areas; the comparison of isolation greening density indicators shows that the isolation greening density in the OSC is higher, indicating that pedestrians in the area are less disturbed by cars and non-motorized vehicles, making the walking environment safer. There is a significant difference in tree canopy coverage, with the OSC ranging between 20% and 38%, while Longjiang ranges between 42% and 93%. The ratio of shrub and tree coverage in the OSC and Longjiang ranges between 6%-35% and 0%-20%, respectively, reflecting better shrub greening in the OSC and a richer landscape. The green view rates in both areas are relatively high, around 50%, with small differences.

4 Establishing of variables of built environmental that affecting subjective perception

The following sections will first utilize factor analysis to extract key attributes and common factors from SD evaluation adjectives, calculating subjective perception scores for streets. Subsequently, through correlation analysis, the built environment variables influencing subjective perception will be selected. By establishing a bivariate correlation model between pedestrian evaluation factor scores of streets and built environment indicators on a street-by-street basis, significant indicators in the built environment that affect pedestrians' psychological perception and emotions will be identified.

4.1 Street walkability analysis of SD evaluation factors

Factor analysis is a statistical method used to extract common factors from a group of variables with overlapping information. It is primarily employed when there are too many variables with certain correlations, grouping factors with strong correlations together to significantly reduce the number of variables and capture most of the original variables' information.

In order to analyze pedestrians' basic impressions of the street environment and their psychological evaluation structure of the streets, this study employed factor analysis to summarize multiple sets of adjective pairs into a few evaluation factors. By calculating the factor loadings of the adjective variables in each group, new factor evaluation scores were obtained. Using SPSS software, we conducted a principal component analysis on 14 SD adjective pairs excluding overall satisfaction, employing the Maximum Variance method for rotating the matrix, resulting in four feature variables and their respective constructions, referred to as new evaluation factors (Table 4). Factor 1 primarily describes pedestrians' preferences for daily social activities on streets, named the "Social" factor. Factor 2 describes the imagery of street spatial environmental elements on pedestrians' psychological level, named the "Spatial Ambiance" factor; Factors 3 and 4 are named "Greenery" and "Facilities," respectively.

By describing common factors with linear combination functions of original variables and using the regression method in the least squares sense to calculate the factor coefficients of each principal component factor (Table 5). When calculating the "Social" factor, adjective pairs such as "monotonous activities-rich activities" and "boring-interesting" had high weights, indicating respondents' perceptions of street social activities, with most other adjective pairs having negative weights, aligning with the actual traits of the factor. Similarly, the adjective pairs with high weights in the "Spatial Ambiance," "Greenery,"

and "Facilities" factors are consistent with their actual characteristics and meanings.

Table 4 Rotated adjective factor loading matrix

	Factors			
	Factor1	Factor 2	Factor 3	Factor 4
Uninteresting-interesting	.859	.168	.008	−.072
Monotonous activities-rich activities	.819	−.009	.099	−.040
Unattractive-attractive	.691	.250	.178	.004
Quiet-lively	.678	−.287	.271	.077
Lack of daily communication-rich daily communication	.468	.289	.461	−.028
Uncomfortable-comfortable	.208	.745	.163	−.124
Noisy-quiet	−.111	.724	−.045	−.351
Chaotic street facade-neat street facade	.013	.676	.219	−.190
Crowded space-spacious space	.084	.671	.227	.139
Dangerous-safe	.187	.546	.506	−.056
Exposed to direct sunlight-cool	.109	.138	.766	.028
Monotonous landscape-rich landscape	.227	.226	.662	−.292
Inconvenient to use-convenient to use	.007	−.042	.035	.844
Lack of facilities-well-equipped facilities	−.074	−.310	−.315	.650
Extraction method: principal component analysis. Rotation method: Kaiser normalization maximum variance method.				
The rotation has converged after 5 iterations.				

Table 5 Factor score coefficient matrix

Factor SD	Main factors			
	Social environment	atmosphere	Green plant	Facilities
Uncomfortable-comfortable	.059	.334	−.135	.059
Noisy-quiet	−.029	.335	−.240	−.137
Cold and quiet-warm and lively	.240	−.217	.147	.004
Monotonous activities-rich activities	.354	−.039	−.129	−.047
Uninteresting-interesting	.398	.077	−.273	−.042
Unattractive-attractive	.274	.088	−.099	.050
Crowded space-spacious space	−.022	.330	−.009	.265
Inconvenient to use-convenient to use	−.025	.143	.090	.687
Monotonous landscape-rich landscape	−.063	−.129	.441	−.160
Chaotic street facade-neat street facade	−.045	.266	−.018	−.003
Dangerous-safe	−.044	.140	.235	.093
Exposed to direct sunlight-cool	−.153	−.141	.607	.094
Lack of facilities-well-equipped facilities	.034	.058	−.130	.453
Lack of daily communication-rich daily communication	.096	.020	.196	.054

Table 6 Street factor score table

District	Social factors	Spatial atmosphere factors	Greenery factors	Facility factors
Olympic sports	0.001	1.002	0.732	0.195
Longjiang	0.121	0.297	0.492	0.124

Through factor score coefficients and variable values, factor score functions were applied to obtain the evaluation scores of each sampled street based on common factors (Table 6). From the table, it can be observed that in terms of social creation, the streets in the Longjiang area are generally slightly better than those in the Olympic Sports Center (OSC), with most streets having ample communication spaces and a balanced distribution of functions. In the evaluation of the spatial ambiance and greenery factors, the OSC area scored higher, with pedestrians perceiving its walking environment to be more comfortable, quiet, and secure. Regarding facility evaluation factors, there isn't a significant difference between the two areas, with most pedestrians finding the use of roadside service facilities convenient.

4.2 Analysis of correlation between street evaluation factor scores and built environment

The street evaluation factor scores were analyzed for their correlation with various indicators across four aspects of the built environment for streets (Table 7).

Overall spatial scale perspective: there was no significant correlation observed between street segment length and the four evaluation factors; street width showed a certain degree of positive correlation with the Spatial Ambiance factor and Greenery factor scores, while the aspect ratio of streets displayed a negative correlation with the Spatial Ambiance factor score. Streets with an aspect ratio of 0.9 had better spatial ambiance values compared to those in the Longjiang area with a ratio of 1.4.

Boundary space perspective: the effective width of sidewalks did not exhibit clear correlations with the four evaluation factors. The transparency coefficient of interfaces showed a positive correlation with the Street Social factor, and the proportion of commercial interactive interfaces correlated positively with scores in both the Street Social and Facilities factors. The density of residential area entrances and exits had a significantly negative correlation with the Spatial Ambiance factor score, while node public square density showed a positive correlation with spatial ambiance. The lack of correlation between the effective width of sidewalks and evaluation factors deviated slightly from expectations, suggesting that the widths of 1.7m in Longjiang and 2.4m in the Olympic Sports Center may both meet pedestrians' needs to some extent, resulting in inconclusive correlation analysis results.

Functional facilities perspective: the quantity of functional facilities exhibited positive correlations with the Social and Facilities factors. The density of pedestrian crosswalks showed a positive correlation with the Spatial Ambiance factor.

Street greenery perspective: the density of boundary greening, isolation greening density, and Greenery factor score all showed positive correlations. The tree canopy coverage rate was negatively correlated with the Greenery factor score, while the green view rate did not show significant correlation. Contrary to past beliefs, scatter plot analysis revealed that the psychological evaluation values of the Greenery factor for sampled streets were positive. High factor scores were observed when the tree canopy coverage rate was in the range of 20%-45%; however, scores decreased beyond 45%. The average green view rate for sampled streets was above 35%, with scores decreasing slightly when it exceeded 60%. The coverage ratio of shrubs and trees showed a positive correlation with Spatial Ambiance, indicating that increasing shrub planting can enhance residents' perception of spatial ambiance.

5 Conclusion

Through factor analysis of pedestrians' psychological evaluations of sampled streets, the psychological evaluation structure was summarized into four main component factors: Social, Spatial Ambiance, Greenery, and Facilities.

From the perspective of urban design and referencing the built environment data and correlation analysis results, we believe that the pedestrian-friendliness of residential street areas can be enhanced in the following aspects: (1) optimizing service facility layout, interface design, and spatial enclosure sensation can Improve the friendliness of the street enclosure interface by enhancing pedestrian perception of social ambiance and street vitality through transparency coefficient of interfaces, proportion of commercial interactive interfaces, and quantity of service facilities. Based on subjective measurements, achieving a transparency coefficient of 0.5 and a commercial interactive interface proportion of 0.22 would result in a non-negative evaluation of social vitality perception on the street. When the street aspect ratio is 0.9, pedestrians perceive a more positive spatial ambiance compared to a ratio of 1.5, reflecting a preference for a more open spatial scale and enclosure sensation among residential pedestrians. (2) Optimizing street cross-sections and boundary space design can ensure effective sidewalk widths and increase isolation greening density and shrub planting density. A street width of around 40m and an effective sidewalk width above 1.7m will evoke a more positive emotional perception of the street ambiance by pedestrians. Pedestrians rate wider streets of 40m higher than Longjiang's 24m wide streets, emphasizing the importance of street cross-section dimensions and boundary space design. Focusing on planting density of isolation and boundary greenery, increasing shrub planting proportion can enhance pedestrians' greenery perception and create a positive street ambiance. The tree canopy coverage rate on sidewalks is more important to pedestrians than the overall street; excessive shading on the street may lead to a slightly oppressive spatial ambiance, highlighting the necessity of a certain sky visibility rate. (3) Enhancing the behavior guidance design of residential entrance spaces and street node public spaces can minimize vehicle traffic disturbances to pedestrian spaces, provide diverse activity areas. High density of residential entrances and exits and roadside bicycle parking areas can create negative perceptions among pedestrians, while increasing the density of node public squares can enhance the perception of spatial ambiance.

Table 7 Correlation analysis results of street built environment dimension indicators and evaluation factor scores

		Specific indicators	Social factor		Spatial atmosphere factor		Greening factor		Facilities factor	
			Correlation coefficient (r)	significance (p-)	Correlation coefficient (r)	significance (p-)	Correlation coefficient (r)	significance (p-)	Correlation coefficient (r)	significance (p-)
Overall spatial scale		Street segment length	-.103	.665	.226	.337	.114	.631	-.301	.197
		Street width	-.030	.900	.555*	.011	.471*	.036	-.109	.649
		Street height-to-width ratio	.301	.198	-.493*	.027	-.108	.650	-.176	.458
Boundary space	Passage space	Sidewalk width	.156	.510	-.078	.743	.235	.319	.274	.243
	Interface	Interface transparency coefficient	.478*	.033	-.265	.259	.003	.990	.195	.409
		Commercial interactive interface ratio	.480*	.032	-.302	.196	.199	.401	.536*	.015
	Others	Neighborhood entrance density	.209	.378	-.683**	.001	.068	.777	.048	.840
		Node public plaza density	-.108	.652	.444*	.050	.301	.197	-.177	.456

Table 7 (continued)

		Specific indicators	Social factor		Spatial atmosphere factor		Greening factor		Facilities factor	
			Correlation coefficient (r)	significance (p-)	Correlation coefficient (r)	significance (p-)	Correlation coefficient (r)	significance (p-)	Correlation coefficient (r)	significance (p-)
Functional facilities	Public service facilities	Number of functional facilities along the street	.495*	.027	−.387	.092	.279	.234	.546*	.013
		Street functional mix degree	.357	.123	−.069	.772	.335	.148	.288	.218
	Public engineering facilities	Bus stop density	−.093	.695	.419	.066	.105	.659	.010	.966
		Street seat density	.035	.882	.146	.538	.268	.253	−.295	.207
		Street bicycle parking area density	.189	.424	−.451*	.046	−.066	.782	.352	.128
		Crosswalk density	−.065	.787	.487*	.029	.132	.578	−.101	.673
Street greening		Boundary greening density	.135	.569	.332	.153	.513*	.021	−.166	.484
		Isolation greening density	.006	.980	.340	.143	.484*	.031	−.304	.193
		Tree canopy coverage ratio	.006	.980	−.351	.129	−.456*	.043	−.135	.569
		Shrubs and trees coverage ratio	.098	.681	.472*	.036	.429	.059	−.125	.600
		Green view rate	.207	.381	−.032	.895	.154	.518	−.147	.537

Note: * - Correlation is significant at the 0.05 level; ** Correlation is significant at the 0.01 level.

Due to limitations in the number of sampled streets and the structured interview questionnaires, there may be some bias in the data analysis results, indicating areas for further refinement in future research. Additionally, the high quality of green planting in Nanjing city and the overall high green coverage in built-up areas resulted in minimal differences in greenery among sampled residential streets. Future research and sample selection should emphasize the differentiation of street characteristics to better represent variations in tree canopy coverage rates and green view rates, further clarifying the impact of tree greening on residents' psychological perceptions. This is an area where the thesis can be improved.

Figure and table sources

All images in the paper were taken or created by the author.

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Construction of Multisensory Landscape and Integration of Soundscape, Smellscape and Lightscape in Traditional Chinese Gardens

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ABSTRACT: This paper proposes the concept of multisensory landscape construction, pointing out that people's perception and appreciation of a landscape is a process of overall impression and judgment formed with a combination of visual, auditory, olfactory, tactile, and even thermal and humid sense. Examples can be found in many famous traditional Chinese gardens. Around the West Lake area, there are famous soundscape scenic spots, e.g., Liu Lang Wen Ying (Orioles Singing in the Willows), Nan Ping Evening Bell (Evening Bell Ringing at the Nanping Hill), Zhejiang Qiu Tao (Autumn Wave of Zhejiang), and Jiu Li Song Tao (Wave of Pine Trees Lasts Nine Miles). There are also some famous lightscape scenic spots, e.g., San Tan Ying Yue (Moon and Candlelight Mirrored in the Lake) and Ping Hu Qiu Yue (Moon over the Peaceful Lake in Autumn). In terms of smellscape, in addition to the famous scenic spot Qu Yuan Feng He (Curved Yard and Lotus Pool in Summer), the West Lake area is also widely planted with osmanthus and other fragrant plants, forming a smellscape in which "late autumn is fragrant with osmanthus flowers and lotus in bloom for miles and miles." At Humble Administrator Garden, there are soundscape scenic spots such as Wu Zhu You Ju (Secluded Residence among Bamboo Bushes) and Liu Ting Ge (Pavilion to Pause and Listen); there are smellscape scenic spots such as the Orchid Field, the Magnolia Courtyard, the Panicum Pavilion, etc.; lightscape scenic spots such as Liu Ying Ge (Hall of Reflecting Shadows) and Ta Ying Ting (Pavilion of Shadow of Tower) can also be found there. In Chengde Summer Resort, there are soundscape scenic spots such as Wan He Song Feng (Wind of Ten Thousand Ravines and Pines) and lightscape scenic spots such as Xi Ling Chen Xia (Morning Sunset on West Ridge), etc.; smellscape scenic spots such as Qu Shui Hua Xiang (Fragrance of Flowers in the Curved Water) and Yuan Xiang Tang (Hall of Fragrance of Far Away) can also be found.

The above classic cases eloquently prove that the creation of multisensory landscape and the integration of them are the valuable experience in traditional Chinese gardens, which play an important role in the achievement of famous landscape.

Therefore, the design of landscape must pay attention to the creation and integration of soundscape, smellscape and lightscape. Another key point of the theory of multisensory landscape construction is that it is necessary to pay attention to both spatial and temporal dimensions so that the constructed landscape can be enjoyed everywhere and at all time periods. In this regard, the creation of the three-scape (specifically refer to soundscape, smellscape and lightscape) can also highlight their regional and temporal characteristics. By analyzing some classic cases of traditional Chinese gardens, this paper proposes that the construction of multisensory landscape and the integration of soundscape, smellscape and lightscape are the valuable experience in traditional Chinese gardens, which are also important for the achievement of famous landscapes and are excellent traditions that we should vigorously inherit and carry forward.

KEY WORDS: *multisensory landscape construction*; *soundscape*; *smellscape*; *lightscape*; *Chinese traditional garden*

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1 Background

Humans possess five sensory organs—eyes, ears, nose, tongue, and skin—responsible for functions of sight, hearing, smell, taste, touch, and temperature and humidity sensations separately, serving as channels for information exchanged with the external environment. It is inevitable that human perception of landscapes is mediated through these five senses, and the information received by these senses is complementary, then the human brain integrates this diverse information to formulate a comprehensive impression and judgment. This can be termed as the process of perceiving a multisensory or holistic landscape. Notably, information received through vision, hearing, and smell is particularly crucial in this process. However, contemporary landscape theories tend to overly focus on visual landscape while neglecting the impact of hearing, smell and touch on landscape perception. Simultaneously, among visual landscapes, the lightscape which is constituted by the light sources and the variations of light and shadow, has not been given particular attention as a unique type. These absences lead to significant deficiencies in landscape planning, design and construction, and consequently diminish people's ability to perceive landscape in their entirety and appreciate their aesthetic qualities fully.

To enhance the quality of living environments, especially the quality of landscapes such as scenic gardens, to better meet the public's demand for high-quality landscapes, to further develop a beautiful China, preserve nostalgia, and create landscapes with national, local and cultural characteristics, and to prevent the pitfalls of a monotonous array of scenes, it is necessary to strengthen research and practice in the theories of multisensory landscape, including soundscape, smellscape, and lightscape. It is essential to advocate for the enhancement of the creation and integration of the three aspects of sound, smell, and light in landscape design and implementation.

2 Concept of the three-scape and the construction of multisensory landscape with the integration of soundscape, smellscape and lightscape

2.1 Soundscape

The concept of "Soundscape" was formally introduced by the Canadian scholar Schafer in the 1960s. The International Organization for Standardization defines "Soundscape" as the auditory environment perceived by individuals, groups, or communities within a given setting. This definition reveals that Soundscape studies focus on both the objective sonic environment and the subjective experience of individuals in the environment. This differentiation is what distinguishes soundscape studies from traditional environmental acoustics. Traditional environmental acoustics primarily concentrates on the objective aspects of the acoustic environment, emphasizing the physical properties of sound waves and their impact on individuals. However, as sound waves serve as carriers of information, the content they convey plays a significant role in individuals' perceptions of sounds, which can vary depending on the listener's social identity and experiences. Additionally, sounds such as music and language possess aesthetic qualities. Therefore, soundscape studies offer a broader and more comprehensive examination of the relationship between the acoustic environment and individuals, as well as society. Soundscape studies view sound as a resource to be utilized, focusing on the use of pleasant sounds that people enjoy listening to in order to create a pleasant acoustic environment while masking the disturbances caused by noise. Soundwalk, as a form of landscape appreciation, provide an innovative way for people to enjoy and explore landscapes.

Although soundscape studies have only been formally introduced for over half a century, ancient China had long recognized the phenomenon and appreciation of soundscape. It has been observed that 28% of the content in the Book of Songs (Shijing) is related to soundscape, with many poems directly titled after soundscape. The Book of Songs also introduced numerous onomatopoeic

words to describe various natural sounds and human social sounds that people enjoy hearing[1]. Ancient Chinese gardens also placed significant emphasis on the creation and appreciation of soundscape.

Soundscape exhibits distinct regional and temporal characteristics. For instance, the sound of tides can only be heard near coastal areas; the sound of the Qiantang Autumn Tide in Hangzhou can only be appreciated near the Qiantang River during the autumn when the Qiantang Tide occurs; various bird songs and insect chirps can only be heard in different locations and seasons, such as the clear examples of summer cicadas and autumn crickets. Therefore, the creation and appreciation of soundscape are inherently characterized by distinctive regional and temporal traits.

2.2 Smellscape

A "Smellscape" refers to the landscape experienced by the sense of smell. The term "Smellscape" is chosen in this paper to emphasize a positive and health-enhancing olfactory environment that is pleasant for people to smell, thus representing the essence of a fulfilling olfactory environment. The concept of "Smellscape" was formally introduced by another Canadian scholar, Porteous, in the 1980s. However, ancient China has long recognized the creation and appreciation of smellscape. The Book of Songs (Shijing) also extensively mentions various fragrant plants, including plum blossoms, phoenix trees, campsis grandiflora, Sichuan pepper, daylily, wormwood, lotus, orchids, peonies and aromatic turmeric root-tuber. In traditional Chinese garden design and construction, fragrant plants have always been considered as an important element of garden landscape, representing important virtual scenes and memory-scape to create the "beyond-reality" ambiance of gardens. Smellscape play an irreplaceable role in shaping and perceiving garden spaces. Like soundwalk, smellwalk serves as a new way to appreciate landscapes.

Smellscape also exhibit distinct regional and temporal characteristics. Different fragrant plants grow in varying geographical and climatic environments, giving them distinct regional characteristics. Additionally, different fragrant plants bloom and emit fragrance in different seasons. For instance, spring peaches, summer lotuses, autumn osmanthus and winter plums represent typical flowers of the four seasons, highlighting the distinct temporal characteristics of smellscape.

2.3 Lightscape

A "Lightscape" refers to a landscape primarily composed of light sources, light and shadow, and their variations, or a landscape that evokes strong visual impressions by the interplay of light sources, light and shadow. A lightscape formed by natural light sources is called a natural lightscape, while one created by artificial light sources is referred to as an artificial lightscape. There is also composite lightscape that combine both natural and artificial light sources. As a distinct type of visual landscape, the concept of "Lightscape" was proposed by the author of this paper in recent years[2]. The inspiration for introducing the concept of lightscape was drawn from the Book of Songs (Shijing). While researching soundscape in the Book of Songs, the author discovered numerous descriptions of illumination phenomena, including references to sunlight, moonlight and starlight as natural illumination, and firelight, lamplight as artificial illumination. Drawing parallels from the concepts of soundscape and smellscape, the concept of "Lightscape" was conceived. Traditional Chinese gardens also place significant emphasis on the creation and appreciation of lightscape. Like soundwalk, lightwalk should be advocated as a novel way of experiencing landscape leisurely.

Similar to soundscape and smellscape, lightscape possess distinct regional and temporal characteristics. For instance, the appearance of a mirage is related to specific geographical locations, geophysical conditions and climate conditions. Thus, it is more likely to occur in places like Chang Island, Penglai, and Huilai. The phenomenon of the aurora borealis exemplifies this concept. The sighting of firefly lightscape is only possible in areas with abundant vegetation and good ecological conditions; furthermore, the cyclical movements of the sun and moon, the rotation of stars and the ever-changing clouds exhibit clear tempo-

ral characteristics.

2.4 Creation of multisensory landscape and integration of the three-scape

This paper introduces the concept of creating multisensory landscape, focusing on two key points. Firstly, it advocates that people's perception and appreciation of landscapes are formed by the synthesis of various elements, including visual, auditory, olfactory, tactile, and thermal-humidity sensations; thus, landscape creation must consider satisfying the sensory experiences and needs of individuals in terms of vision, hearing, smell, taste, and bodily sensations. Among these, the elements of sight, sound, and smell are particularly indispensable. Therefore, promoting the creation and integration of soundscape, smellscape and lightscape is one of its core components. Secondly, the creation of landscapes must consider both spatial and temporal dimensions, ensuring beauty everywhere and at all times[3]. Soundscape, smellscape and lightscape all possess distinct regional and temporal characteristics; thus, they can play pivotal roles in landscape creation with these two dimensions.

Introduction of the concept of "Multisensory Landscape" and the integration of the "Three-scape" explore a new approach to enhancing the quality of human living environment, particularly the quality of landscape. In the existing studies, we have observed that renowned classical Chinese garden landscapes, in addition to well-designed architectural and natural landscape, also incorporate diverse elements of sound, fragrance and light, presenting rich sensory experiences for sight, hearing, and smell. They achieve the integration of the three-scape by providing diverse information and eliciting aesthetic satisfaction from various perspectives, consequently constructing healthy landscape that evoke nostalgia. Below, we will further elaborate on this concept by several exemplary classical Chinese garden landscapes that excel in the creation of multisensory landscape and the integration of the three-scape.

3 Classic cases of multisensory landscape creation and integration of the three-scape in Chinese classical gardens

3.1 West Lake, Hangzhou

West Lake in Hangzhou is a renowned scenic spot in China that has long been referred to as a paradise in the old saying "up above there is paradise, down here there are Suzhou and Hangzhou." The widespread acclaim and enduring fame of West Lake can be attributed not only to its exceptional natural and architectural landscapes but also to its emphasis on the creation of multisensory landscapes that integrate the three senses of sound, fragrance, and light. In West Lake, there are famous soundscapes such as the Orioles Singing in the Willows (Figure 1) and the Evening Bell at Nanping, where visitors can appreciate the natural and cultural soundscapes of bird songs and temple bells. Historically, there are renowned soundscapes like the Autumn Sounds of Zhejiang and the Nine Miles' Sounds of Pines, which are part of the Ten Views of the Qiantang River[4,5], for visitors to listen to the natural sounds of Qiantang waves and pine winds. In terms of light, West Lake features prominent lightscapes like the Three Pools Mirroring the Moon and the Autumn Moon over Pinghu Lake. Among these, the Three Pools Mirroring the Moon is a creatively designed lightscape where three stone pagodas were built on the lake(Figure 2), each with a hollow belly and five evenly spaced circular holes in their spherical bodies; on moonlit nights, thin paper is pasted on the holes, and lamps are lit inside the pagodas; the bright moonlight is reflected on the lake surface through the holes, creating multiple images of the moon, a captivating sight celebrated as the "Top Scenic Spot of West Lake." The Autumn Moon over Pinghu Lake is another famous moon-watching site. From August 14th to 16th each year, the Mid-Autumn Moon Viewing event is held at Pinghu Lake, making it a traditional and picturesque experience to admire the beauty of the autumn moon at West Lake. In terms of smellscape, apart from the famous Quyuan Fenghe, one of the Ten Views of West Lake (Figure 3), which lets visitors to smell the fragrance of lotus flowers, West

Lake also plants osmanthus and other fragrant plants to create a delightful scene known as the "Osmanthus in Autumns and Lotus Flowers for Ten Miles," a subject of praise by renowned poets such as Liu Yong. It is evident that the creation and integration of the three-scape contribute to the continuous allure and international fame of the West Lake landscape, making it a shining symbol of beauty both at home and abroad.

Figure 1 Orioles Singing in the Willows, West Lake

Figure 2 Three Pools Mirroring the Moon, West Lake

Figure 3 Quyuan Fenghe, West Lake

3.2 Humble Administrator's Garden

Representing classical gardens in Suzhou, the Humble Administrator's Garden (Figure 4) also places significant emphasis on the creation and integration of the three-scape. In the Humble Administrator's Garden, there are soundscapes such as the Wuzhu Youju (secluded dwelling between phoenix trees and bamboos), Ting Songfeng Chu (pavilion for listening to the wind among pines), Ting Yuxuan (pavilion for listening to the rain) and Liutingle (pavilion for lingering sounds), for visitors to appreciate the soothing sounds produced by the wind and rain interacting with various vegetation, such as the melodies of bamboo and pine, and to experience the artistic conception of "listening to the raindrops on withered lotus leaves." In terms of smellscape, there are scenic spots like Yuanxiang Tang (distant fragrance hall), Lanwan (orchid garden), Yulanyuan (magnolia courtyard), Shuxiang Guan (millet fragrance house), Xuexiang Yunweiting (pavilion of snow fragrance and cloud elegance), Shanghe (appreciating lotus) and Haitang Chunwu (spring lodge of begonia), where visitors can enjoy the scent of orchids, magnolias, plums, lotuses, and begonia flowers blooming in different seasons. Regarding the lightscape, there are points of interest like Daoyinglou (reflection tower) and Tayingting (pavilion of tower shadow), where visitors can observe the reflections and light variations on the water, as well as Linglongguan (exquisite pavilion) that lets people to appreciate the interplay of moonlight in the bamboo grove, creating a captivating scene known as "moonlight penetrating the green bamboo, elegant and exquisite." It is the harmonious integration of the three-scape and the diverse offerings in these aspects that have contributed to the Humble Administrator's Garden earning its reputation as one of the Four Great Gardens of China.

Figure 4 Seasonal changes in the Humble Administrator's Garden (from left to right: spring, summer, autumn, winter)

3.3 Chengde Mountain Resort

Chengde Mountain Resort, another famous scenic garden and resort area listed amongthe Four Great Gardens of China, exemplifies the importance of integrating and showcasing the three-scape experiences (Figure 5). In terms of soundscape, the resort features scenic spots such as Wanhe Songfeng (pine winds in countless valleys), Fengquan Qingting (clear springs with the sound of wind), Yingzhuan Qiao Mu (singing birds among tall trees) and Nuanliu Xuanbo (warm streams with bustling waves), for visitors to appreciate the sounds of pine rustling, spring water flowing, waves crashing and the melodious singing of yellow warblers. Regarding the smellscape, Chengde Mountain Resort offers scenic spots like Qushui Hexiang (fragrance of lotus on winding waters), Xiangyuan Yiqing (fragrance spreading far and wide), Lihua Ban Yue (pear blossoms under the moon), and Jinlian Yingri (golden lotus reflecting the sun).

In terms of the lightscape, the resort provides scenic spots such as Xiling Chenxia (morning glow over the Western Ridge), Chuifeng Luozhao (setting sun behind the Hammer Peak), Yunfan Yuefang (moonlit cruise under the clouds) and Changhong Yinlian (rainbow drinking over the river), for visitors to observe phenomena like morning glow, sunsets, clouded moons and rainbows. The aforementioned sites of Qushui Hexiang, Lihua Ban Yue and Jinlian Yingri are examples of spots that combine soundscape, smellscape and lightscape. Moreover, the Moonlight and River Sound spot on Golden Mountain Island is a prime example of the fusion of soundscape and lightscape. It is evident that the integration and completeness of the three-scape have played a crucial role in establishing Chengde Mountain Resort as a renowned and significant destination in the realm of scenic gardens and resorts.

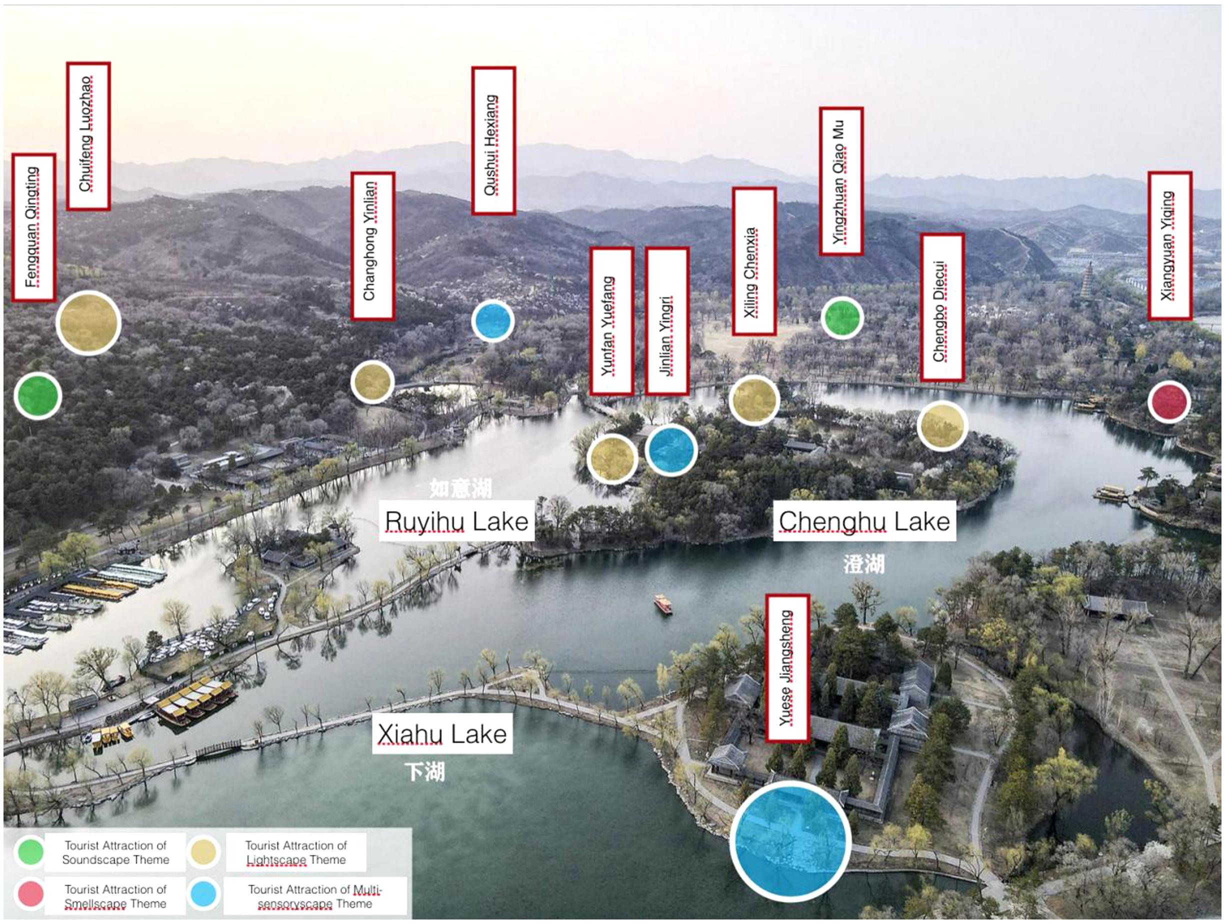

Figure 5 Schematic diagram of some tourist attractions of soundscape, lightscape and smellscape in Chengde Mountain Resort

4 Conclusion

This paper introduces the concept of creating multisensory landscape and emphasizes that people's perception and appreciation to landscapes are formed with the synthesis of visual, auditory, olfactory, tactile, thermal and other sensory inputs, leading to an overall impression and judgment process. Among these, visual, auditory, and olfactory information are particularly crucial and indispensable. Therefore, the design and construction of landscape must prioritize the creation and integration of sound, fragrant, and light aspects. Another key aspect of the theory of creating multisensory landscape is the simultaneous consideration of both spatial and temporal dimensions of landscape, ensuring that the constructed landscapes are consistently appealing in all places and at all times. In this regard, the creation of the three-scape can also highlight the regional and temporal characteristics of landscape. Traditional modern landscape theories often overly emphasize visual landscape as well as spatial dimension, neglecting the construction of soundscape and smellscape, as well as lightscape, the particular aspect of visual landscape, and overlooking the temporal dimension, leading to significant shortcomings in landscape creation. Therefore, the introduction of the theory of creating multisensory landscape, with a focus on the creation and integration of the three sensory (visual, auditory, and smell) experiences, represents a significant improvement in the quality of living environment, particularly in landscape quality, exploring a new access and perspective. This concept holds important guiding principles for further developing a beautiful China, preserving nostalgia, especially in the construction of gardens, tourist areas, distinctive towns, and beautiful rural areas. Based on the analysis of several classic Chinese traditional garden cases, this paper eloquently proves that the creation of multisensory landscape and the integration of the three-scape are valuable experiences in traditional Chinese gardens. They play a crucial role in the creation of famous landscapes and should be vigorously inherited and promoted as an excellent tradition.

Figure and table sources

Figure 1 and 3: http://www.5a4a3a.com/hz.htm.

Figure 2: https://kknews.cc/travel/p5vknez.html.

Figure 4: https://www.meipian.cn/2vyl4vpd.

Figure 5: The image is processed by the author based on the picture from http://www.bishushanzhuang.com.cn/index.php/scenic/pic_list/id/39.html.

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